Benthic TMDL for Quail Run, Rockingham County, Virginia

Submitted by:

Virginia Department of Environmental Quality

Prepared by:

Department of Biological Systems Engineering, Virginia Tech

February 6, 2003

Project Personnel

Virginia Tech, Department of Biological Systems Engineering

Brian Benham, Assistant Professor
Kevin Brannan, Research Associate
Theo A. Dillaha, Professor
Saied Mostaghimi, Professor
Jeff Wynn, Research Associate
Gene Yagow, Research Scientist
Rebecca Zeckoski, Research Associate

Virginia Department of Environmental Quality

Sandra Mueller, TMDL Project Manager
Larry Hough
Jutta Schneider
Joe Winfield
Ron Phillips

Virginia Department of Conservation and Recreation

Mike Shelor, TMDL Project Coordinator

For additional information, please contact:

Virginia Department of Environmental Quality (VADEQ)
Water Quality Assessment Office, Richmond: Charles Martin, (804) 698-4462

BSE Department: Saied Mostaghimi, Project Director, (540) 231-7605

Table of Contents

List of Tables

List of Figures

CHAPTER 1: EXECUTIVE SUMMARY

1.1. Background

A part of the Potomac and Shenandoah River basin, Quail Run watershed (Watershed ID VAV-B35R) is located in Rockingham County, Virginia, about 5 miles east of Harrisonburg; the watershed contains the Massanutten Resort. The watershed is 3,513 acres in size. The watershed extends from the eastern divide of the Massanutten Mountain down into the valley of the South Fork of the Shenandoah River valley. Quail Run flows east and discharges into Boones Run, which in turn discharges into the South Fork of the Shenandoah River (USGS Hydrologic Unit Code 02070005). Land use is fairly evenly divided between agriculture (40%, predominately pasture in the lowlands) and forest (42%, primarily in the headwaters on Massanutten Mountain). The remaining 18% of the watershed area is divided between high and low intensity urban developments. Development is concentrated in the area of the Massanutten development in the western portion of the watershed.

Quail Run is listed as impaired on Virginia's 1998 Section 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 1998) due to water quality violations of the General Standard for Aquatic Life Use (listed as a benthic impairment) for a stream length of 5.07 miles. The impaired segment begins at the Massanutten sewage treatment plant (STP) and continues downstream to its confluence with Boones Run. Biological monitoring has been performed by VADEQ in the Quail Run watershed from October 1996 to present at several benthic monitoring stations. This monitoring is supplemented by ambient water quality monitoring sites and special study sites. The Quail Run TMDL was originally targeted for completion during 2006-2008, but the schedule was accelerated because of the construction of a new sewage treatment plant.

1.2. Sources of Impairment

A point source discharge of ammonia, residual chlorine, and chlorination by-products from the Massanutten Public Service Corporation sewage treatment plant (STP) was identified as the predominate source of benthic impairment.

1.3. Existing Conditions

The impairment was found to be the result of excessive ammonia discharges and the use of breakpoint chlorination treatment by the existing Massanutten Public Service Corporation STP. Nonpoint sources also contribute to the ammonia load, but their contribution is less than 4% of the ammonia load to the stream. The existing STP will be replaced by a new STP in 2003.

1.4. Future Conditions

The TMDL was developed for future conditions that will result from the construction of the new Massanutten Public Service Corporation STP. The new permit is tiered. The TMDL is developed for the 2.0 MGD permitted flow.

1.5. Allocation Scenarios

For the ammonia TMDL, the point source loading from the STP was identified as the predominant source and a 5% margin of safety is used. For the total residual chlorine TMDL, the point source loading from the STP was identified as the sole source of the impairment, the TMDL allocation is very specific and a margin of safety was implicitly included in the wasteload allocation.

Table 1-1. TMDLs for Quail Run with permitted Massanutten STP discharge of 2.0 MGD[1].

Pollutant	TMDL (kg/yr)	WLA[2] (kg/yr)	LA (kg/yr)	MOS (kg/yr)
Ammonia	7,857	7,185	279	393
Total residual chlorine	27.63	27.63	0	0

[1] The Massanutten STP permit is tiered. At the other permitted discharge of 1.5 MGD, the WLA for ammonia and total residual chlorine are 5389 kg/yr and 20.73 kg/yr, respectively.

[2] The wasteload allocations are obtained by multiplying the permitted STP flow by the permitted effluent concentrations of 2.6 mg/L for ammonia and 0.01 mg/L for total residual chlorine (3.7854 L/gal conversion factor). These permitted values are based on monthly and weekly averages, and the basis for this is documented in the permit fact sheets.

1.6. Implementation

A new STP that will meet the above TMDL allocations is being constructed and should be operational by May 15, 2003. The existing STP, believed responsible for the impairment, will then be closed in accordance with an approved facility closure plan.

1.7. Reasonable Assurance of Implementation

The Department of Environmental Quality will continue to monitor Quail Run in accordance with its benthic and ambient monitoring programs. VADEQ will continue to use data from these monitoring stations to evaluate benthic macroinvertebrate health and the effectiveness of the TMDL in attaining and maintaining water quality standards.

It is recommended that a forested riparian canopy be reestablished in the disturbed riparian zone downstream of the STP to increase stream shading during the late spring to fall period and avert nutrient related periphyton growth problems. The Massanutten development is currently investigating costs associated with reestablishing the riparian canopy and is expected to enter into an agreement with VADEQ to partially restore the riparian canopy downstream of the STP.

Once developed, VADEQ intends to incorporate the TMDL implementation plan into the appropriate Water Quality Management Plan (WQMP), in accordance with the CWA's Section 303(e). In response to a Memorandum of Understanding (MOU) between EPA and VADEQ, VADEQ also submitted a draft Continuous Planning Process to EPA in which VADEQ commits to regularly updating the WQMPs. Thus, the WQMPs will be, among other things, the repository for all TMDLs and TMDL implementation plans developed within a river basin.

1.8. Public Participation

Public participation was elicited at every stage of the TMDL development in order to receive inputs from stakeholders and to apprise the stakeholders of the progress made. A single public meeting, noticed on January 27, 2003, was held on February 10, 2003 at Spotswood High School in Penn Laird, Virginia to inform the stakeholders of TMDL development process and to obtain feedback on the draft of the TMDL report. Copies of the TMDL report, presentation materials, and diagrams outlining the development of the TMDL were available for public distribution at the meeting. Approximately 18 people attended the meeting. The public comment period ended on March 12, 2003.

CHAPTER 2: INTRODUCTION

2.1. Background

2.1.1. TMDL Definition and Regulatory Information

Section 303(d) of the Federal Clean Water Act and the U.S. Environmental Protection Agency's (USEPA) Water Quality Planning and Management Regulations (40 CFR Part 130) require states to identify water bodies that violate state water quality standards and to develop Total Maximum Daily Loads (TMDLs) for such water bodies (USEPA, 1998). A TMDL reflects the total pollutant loading a water body can receive and still meet water quality standards. A TMDL establishes the maximum allowable pollutant loading from both point and nonpoint sources for a water body, allocates the load among the pollutant contributors, and provides a framework for taking actions to restore water quality.

2.1.2. Impairment Listing

Quail Run (Segment ID VAV-B35R-03) was first listed as severely impaired on Virginia's 1998 Section 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 1998) due to water quality violations of the General Standard for Aquatic Life Use (listed as a benthic impairment). The 1998 report indicated that Quail Run was not supporting its designated Aquatic Life Use. The Massanutten sewage treatment plant was identified as the source of the impairment and "toxic compounds in the effluent such as chlorine and ammonia" were believed to be the cause of the impaired ratings. Quail Run was again listed as impaired in Virginia's 2002 Section 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 2002). The 2002 report indicated that Quail Run was moderately impaired, partially supporting its designated Aquatic Life Use, and that the Massanutten STP was the impairment source. In addition, the stream was classified as threatened because of high total phosphorus values.

The Virginia Department of Environmental Quality (VADEQ) has identified Quail Run as violating the General Standard for a stream length of 5.07 miles, beginning at the Massanutten sewage treatment plant (STP) and continuing downstream to its confluence with Boones Run. The Quail Run TMDL was originally targeted for completion in 2006-2008, but the schedule was moved up because of the construction a new STP.

2.1.3. Watershed Location and Description

A part of the Potomac and Shenandoah River basin, Quail Run watershed (Watershed ID VAV-B35R) is located in Rockingham County, Virginia, about 5 miles east of Harrisonburg; the watershed contains Massanutten Resort (Figure 2-1). The watershed is 3,513 acres in size. The watershed extends from the eastern divide of the Massanutten Mountain down into the valley of the South Fork of the Shenandoah River valley. Quail Run flows east and discharges into Boones Run, which in turn discharges into the South Fork of the Shenandoah River (USGS Hydrologic Unit Code 02070005). The South Fork of the Shenandoah River is a tributary of the Shenandoah River, which drains to the Potomac River. The Potomac River discharges into the Chesapeake Bay. Land use is fairly evenly distributed between agriculture (30% pasture and 10% cropland, predominately pasture in the lowlands) and forest (42%, primarily in the headwaters on Massanutten Mountain). The remaining 18% of the watershed area is divided between high and low intensity urban developments. The three benthic monitoring stations in the watershed are located upstream of most of the agricultural land in the watershed as shown inFigure 2-2. Development is concentrated in the area of the Massanutten development in the western portion of the watershed as indicated inFigure 2-3.

The number of permanent residents in the Quail Run watershed, estimated from the 2000 census, is approximately 1,346, of which 316 are not connected to the Massanutten Public Service Authority sewer system. However, the census numbers do not accurately represent the actual number of people in the watershed well because of the presence of the various developments associated with the Massanutten Resort. The resort complex has a large number of vacation homes and time-shares. In addition, an estimated average of 3,500 people visit the resort each day. Currently, there are approximately 2,000 housing units (homes and timeshares) associated with the development and the number of units is expected to increase by approximately 1,900 over the next 10 to 15 years. Most of the existing properties associated with the resort and all of the expected future properties will be serviced by the Massanutten Public Service Authority sewer system. A new sewage treatment plant, to be discussed later, became operational in 2003 in anticipation of this expected growth.

Livestock and wildlife numbers in the watershed were enumerated through surveys of land owners and assessment of wildlife habitat. As indicated in Table 2-1, estimated livestock and wildlife numbers are relatively low in the watershed and would not be expected to be a significant threat to water quality.

Table 2-1. Estimated Quail Run livestock and wildlife populations

Animal	Population
Deer	165
Raccoon	99
Muskrat	165
Beaver	8
Wild Turkey	29
Goose - summer	49
Goose - winter	68
Duck - summer	39
Duck - winter	59
Dairy cows	400
Beef	369
Poultry	1,726,188*

* per year

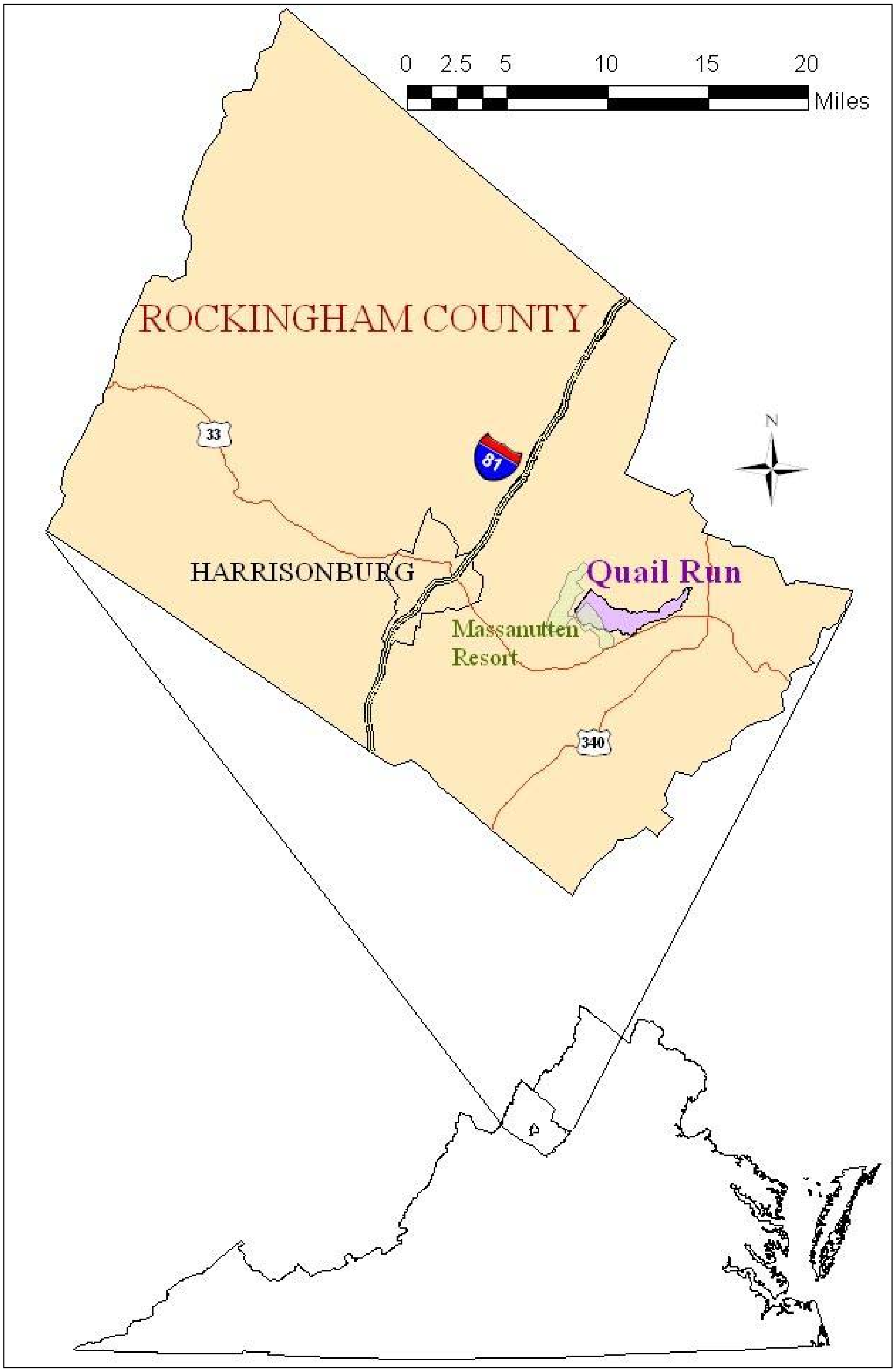

Figure 2-1. Location of the Quail Run watershed.

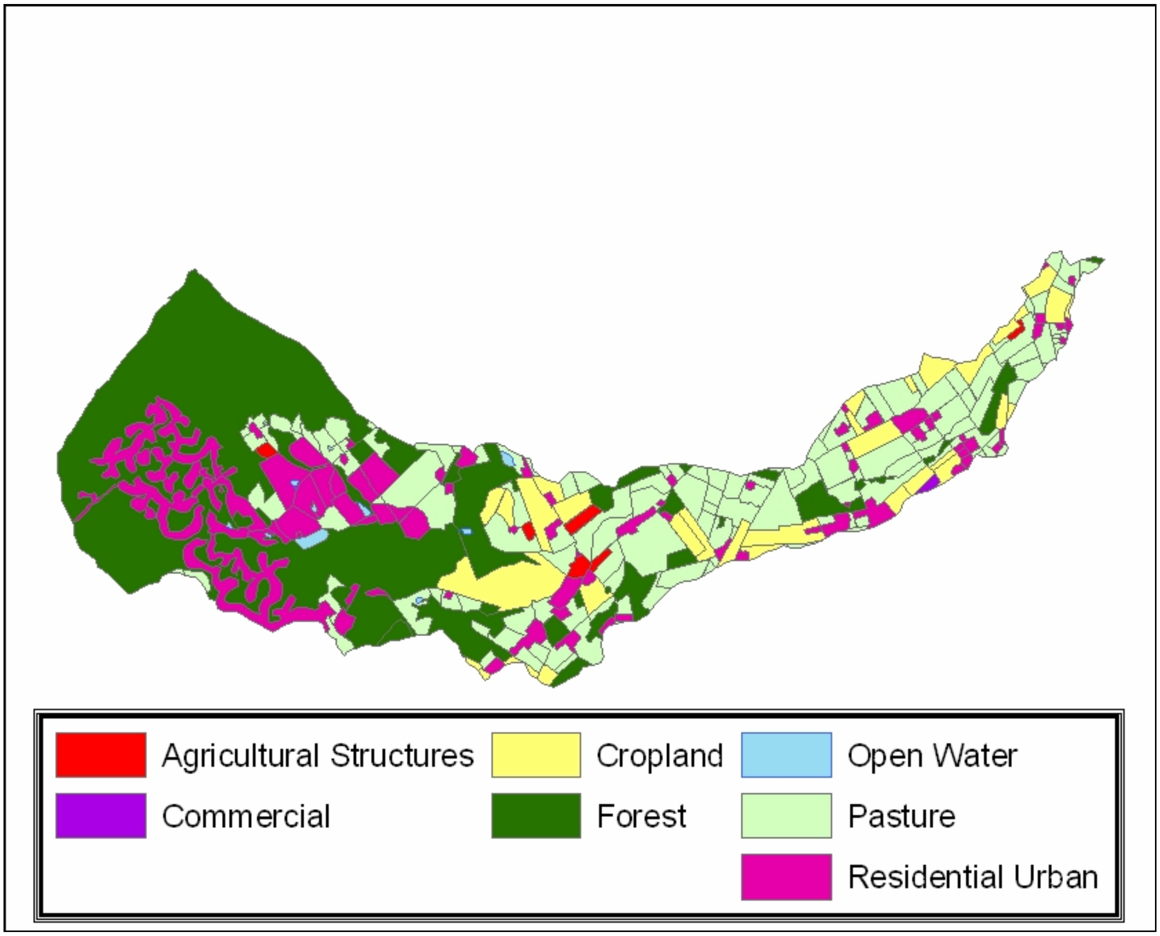

Figure 2-2.Quail Run land use

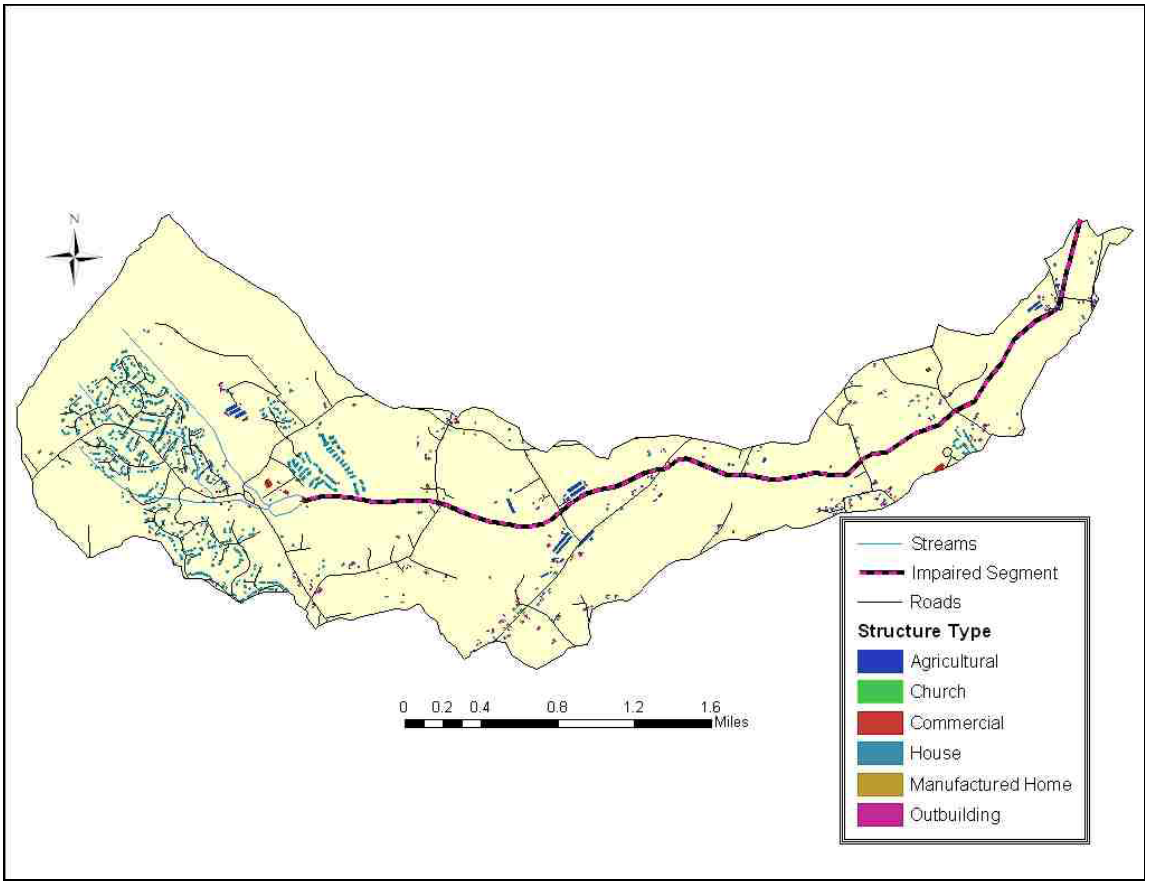

Figure 2-3. Development in the Quail Run watershed

2.1.4. Pollutants of Concern

Pollution from both point and nonpoint sources can lead to a violation of the General Standard for Aquatic Life Use. This violation is assessed on the basis of measurements of the benthic macro-invertebrate community in the stream, with pollution impacts referred to as a benthic impairment. Water bodies having a benthic impairment do not fully support the aquatic life use designated for Virginia's waters.

2.2. Designated Uses and Applicable Water Quality Standards

The general standard for a water body in Virginia (9 VAC 25-260-20) states:

> "A. All state waters, including wetlands, shall be free from substances attributable to sewage, industrial waste, or other waste in concentrations, amounts, or combinations which contravene established standards or interfere

directly or indirectly with designated uses of such water or which are inimical or harmful to human, animal, plant, or aquatic life.

Specific substances to be controlled include, but are not limited to: floating debris, oil scum, and other floating materials; toxic substances (including those which bioaccumulate); substances that produce color, tastes, turbidity, odors, or settle to form sludge deposits; and substances which nourish undesirable or nuisance aquatic plant life. Effluents which tend to raise the temperature of the receiving water will also be controlled." (SWCB, 2002)

The first paragraph of this standard describes the designated uses for a water body in Virginia. Quail Run is violating the General Standard for Aquatic Life Use, and thus has a general standard (benthic) impairment.

The biological monitoring program in Virginia is conducted by the Department of Environmental Quality (VADEQ). Evaluations of monitoring data from the program focus on the benthic (bottom-dwelling) macro (large enough to see) invertebrates (insects, mollusks, crustaceans, and annelid worms) and are used to determine whether or not a stream segment is supporting the aquatic life use. Changes in water quality generally result in changes in the types and numbers of the benthic organisms that live in streams and other water bodies. Besides being the major intermediate constituent of the aquatic food chain, benthic macro-invertebrates are "living recorders" of past and present water quality conditions. This is due to their relative immobility and their variable resistance to the diverse contaminants that can be introduced into streams. The community structure of these organisms provides the basis for the biological analysis of water quality. Qualitative and semi-quantitative biological monitoring has been conducted by VADEQ since the early 1970's. The USEPA Rapid Bioassessment Protocol (RBP) II was employed beginning in the fall of 1990 to utilize standardized and repeatable methodology. For any single sample, the RBP produces water quality ratings of "non-impaired," "slightly impaired," "moderately impaired," and "severely impaired." In Virginia, benthic samples are generally taken and analyzed twice a year, in the spring and in the fall.

The procedure evaluates the benthic macro-invertebrate community by comparing ambient monitoring network stations to reference sites. A reference site is one that has been determined to be representative of a natural, unimpaired water body. The RBP evaluation also accounts for the natural variation noted in streams in different ecoregions. One additional product of the RBP evaluation is a habitat assessment. This assessment provides information on the comparability of each stream station to the reference site.

Determination of the degree of support for the aquatic life use is based on conventional water column pollutants (DO, pH, temperature), sediment and nutrient screening value analyses, biological monitoring data, and the best professional judgment of the regional biologist, relying mostly on the most recent data collected during the current 5-year assessment period. In Virginia, any stream segment with an overall rating of “moderately impaired” or “severely impaired” is placed on the state’s 303(d) list of impaired streams (VADEQ, 2002).

CHAPTER 3: WATERSHED CHARACTERIZATION

3.1. Water Resources

Most streams in the Quail Run watershed flow seasonally/intermittently. Banks are typically steep and deep, with a trapezoidal channel cross-section. Aquifers of the headwaters are dominated by the sandstone and shale of Massanutten Mountain, while the lower reaches of Quail Run are carbonaceous underlain by sandstones and shales (Roberts and Bailey, 2003). The presence of karst features and agricultural use result in a high potential for groundwater pollution (VWCB, 1985).

3.2. Ecoregion

The Quail Run watershed is located in the Central Appalachian Ridges and Valleys Level III Ecoregion. It is located primarily in the Northern Limestone/Dolomite Valleys Level IV Ecoregion, with a small portion located in the Northern Sandstone Ridges Level IV Ecoregion. The Central Appalachian Ridges and Valleys Ecoregion is characterized by generation from a variety of geological materials (primarily limestone, dolomite, and sandstone in Quail Run). The Level III Ecoregion has numerous springs and caves. The ridges tend to be forested, while limestone valleys are composed of rich agricultural land (USEPA, 2002). The Northern Limestone/Dolomite Valleys Level IV Ecoregion has fertile land and is primarily agricultural. Steeper areas have scattered forests composed mainly of oak trees. The Northern Sandstone Ridges Level IV Ecoregion has steep peaks. Streams have steep slopes and a tendency toward acidity. The ecoregion is composed primarily of Appalachian Oak Forest or Oak-Hickory-Pine forest (Woods *et al.*, 1999).

3.3. Soils and Geology

The main soil associations found in the Quail Run watershed are Drall-Laidig, Laidig-Buchanan-Berks, Chilhowie-Edom, and Frederick-Lodi-Rock Outcrop (SCS, 1982). The Drall-Laidig and Laidig-Buchanan-Berks associations are formed from residual or colluvial material weathered from sandstone, shale, or greenstone. The Chilhowie-Edom and Frederick-Lodi-Rock Outcrop soil associations are formed in residual material from weathered limestone, dolomite, and calcareous shale. The rock outcrops of the Frederick-Lodi-Rock Outcrop association consist mainly of limestone and dolomite (SCS, 1982). Soils in the watershed are characterized as deep to moderately deep well drained soils with clayey (Frederick-Lodi-Rock Outcrop, Chilhowie-Edom) or loamy (Drall-Laidig, Laidig-Buchanan-Berks) subsoils. The Drall-Laidig soils are deep and well or excessively drained with loamy subsoils. The permeability of Drall soils is rapid and surface runoff is slow. The Laidig soils have moderately slow permeability with medium surface runoff potential. Laidig-Buchanan-Berks soils are moderately deep to deep, with drainage that ranges from well-drained to somewhat poorly drained and loamy subsoils. The permeability of Buchanan and Berks soils is moderate with medium surface runoff. The Chilhowie-Edom soils are moderately deep to deep, well-drained soils with clayey subsoils. The permeability of Chilhowie soils is slow, and surface runoff ranges from medium to very rapid. The permeability of Edom soils is moderately slow and the surface runoff ranges from medium to rapid. The Frederick-Lodi-Rock outcrop (silty loam) soils are deep and well drained with clayey subsoil and areas of rock outcrop. Permeability of Frederick and Lodi soils is moderate with medium to rapid surface runoff. These soils are found on gently sloping to steep topography (SCS, 1982). In upland areas, the Frederick-Lodi-Rock outcrop soils are underlain by deep limestone and dolomitic limestone bedrock (SCS, 1982). This karst bedrock has numerous cracks, fissures and caves capable of transporting water and contaminants considerable distances before resurfacing as spring water or baseflow.

3.4. Climate

Because there are no weather stations within the watershed, climate was characterized based on the meteorological observations made by the National Climatic Center station at Dale Enterprise, Virginia, located 11.1 miles WNW of the watershed. Average annual precipitation is 36.12 inches with 51% of the precipitation occurring from May-September, which includes the crop-growing season. Average annual snowfall is approximately 25 inches. Average annual daily temperature is 53.2°F. The highest average daily temperature of 73.2°F occurs in July, while the lowest average daily temperature of 32.5°F occurs in January (SERCC, 2000).

3.5. Land Use

The land use areas in Quail Run were digitized from digital orthophoto quarter quadrangles (DOQQs) originally produced by the United States Geological Survey (dated March 12, 1997) and converted to MrSid format by the Virginia Economic Development Partnership in October of 1999. Seven major land use categories were found in the Quail Run watershed, as can be seen in Table 3-1 and Figure 2-2.

Forest comprises most of the area in the Quail Run watershed and covers about 42.1% of the total watershed area (Table 3-1). Pasture covers 30.1% and cropland accounts for about 10.4% of the watershed area. Commercial and residential uses (commercial, farmstead, and high and low density residential) account for 16.9% of the total area, and the remaining area is classified as open water.

Table 3-1. Land use distribution in the Quail Run watershed.

Land use	Area	
	Acres	%
Cropland	366	10.4
Pasture	1057	30.1
Open Water	15	0.4
Farmstead	126	3.6
Low Density Residential	390	11.1
High Density Residential/Commercial	79	2.2
Forest	1480	42.1
Total	3513	100

3.6. Point Sources

There is one point source, the Massanutten Public Service Corporation sewage treatment plant (Permit No. VA0024732, VADEQ Monitoring Station QAL005.07) in the watershed. The STP outfall is located where route 644 crosses Quail Run, as shown in Figure 3-1, 5.07 miles upstream of the confluence of Quail Run with Boones Run. A new STP is partially constructed and the first train (half) of the STP became operational in March 2003. The new STP will become fully operational during the spring or summer of 2003 when the second train of the STP goes on line. To better understand the nature of the point source loading to Quail Run from the Massanutten STP, it is necessary to describe the existing STP (pre 2003), when all the water quality monitoring data were collected, as well as the new STP, which will be more characteristic of future point source loadings. When the new STP is fully operational, the existing STP will be closed in accordance with an approved facility closure plan.

3.6.1. Existing Sewage Treatment Plant (pre 2003)

The existing wastewater treatment plant is located just off of State Route 644 near Elkton, Virginia, as is shown in Figure 3-1. The 7-day 10-year low flow at the STP is estimated to be 0.045 cfs. With a current permitted discharge of 1.16 cfs, the STP effluent constitutes almost the entire streamflow during low flow conditions.

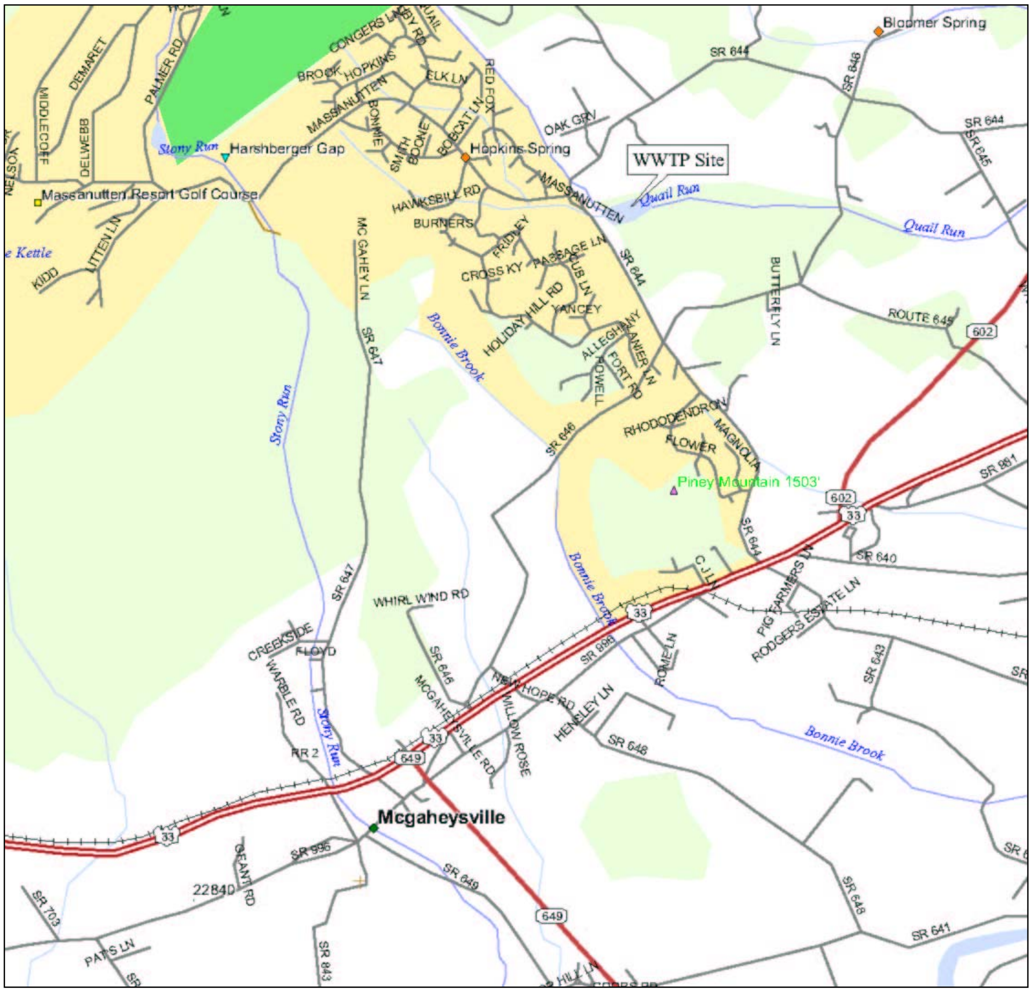

Figure 3-1. Location of Massanutten STP within Quail Run watershed.

The existing STP process is as follows. The wastewater enters the plant through a flow-measuring flume. The wastewater then enters a four cell extended aeration treatment lagoon system. The partially treated wastewater from the lagoons is then further treated with the following processes: a nitrification reactor (to convert ammonia to nitrate), tertiary filters (to remove solids), chlorination (to disinfect the effluent) and dechlorination (to remove chlorine residuals after the effluent has been disinfected). Backwash water containing filtered solids from the tertiary filters is stored in a holding basin and pumped back to the inlet of the aerated lagoons. During the colder months of the year, the biological activity (treatment efficiency) in the lagoons and the nitrification reactor is reduced because of the lower temperatures, which results in higher concentrations of ammonia in the STP effluent. To remove the excess ammonia during the colder months, breakpoint chlorination is used to breakdown the ammonia in the wastewater. Breakpoint chlorination converts the ammonia to chloramines and finally nitrous oxide and nitrogen gas.

The existing plant currently serves about 1,850 connections. These include approximately 850 residential lots and townhouses with permanent residents (may be a secondary home and not included in 2000 census data) and the remainder are time-shares with variable occupancy. The balance of the existing service is allocated to light commercial usage. New homes and timeshares are being constructed continuously.

Figure 3-2 provides a schematic view of the treatment processes in the existing STP.

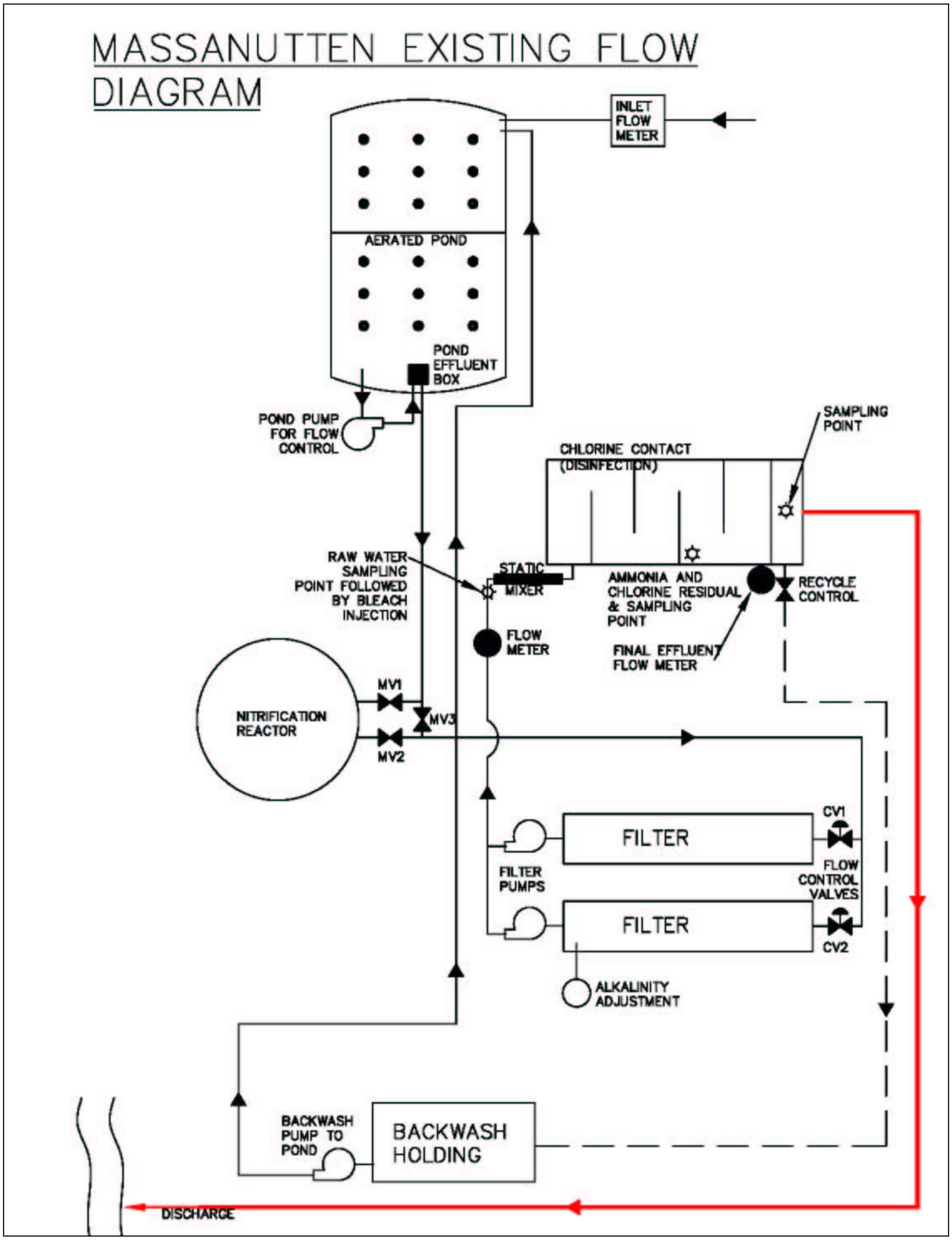

Figure 3-2. Schematic of existing STP (pre 2003).

The existing facility is designed to treat 750,000 gallons per day of wastewater to the effluent standards described in Table 3-2.

Table 3-2. Permitted effluent characteristics for existing STP (effective July 2002).

Permitted Effluent Characteristics	Monthly Average	Weekly Average	Minimum	Maximum
Fecal Coliform Bacteria				200/100 mL
BOD_5 (Biochemical Oxygen Demand)	10 mg/L and 28.39 kg/day	15 mg/L and 42.58 kg/day		
Total Suspended Solids	30 mg/L and 85.2 kg/day	45 mg/L and 128 kg/day		
Ammonia	2.6 mg/L	2.6 mg/L		
Dissolved Oxygen			7.5 mg/L	
pH (standard units)			6.5	9.5
Total Residual Chlorine	0.01 mg/L	0.01 mg/L		
Di-2-Ethylhexyl Phthalate	69.7 μg/L	69.7 μg/L		
Total Cyanide	7.9 μg/L	7.9 μg/L		

3.6.2. New Sewage Treatment Plant

Because of growth in the Massanutten Public Service Corporation STP service area, some operational problems with the existing STP, and the need to reduce the discharge of some wastewater constituents to Quail Run, the existing STP is being replaced by a new STP, which will be in operation in February 2003. The new STP will be located adjacent to the existing STP, but on the other side of Quail Run as shown in Figure 3-3.

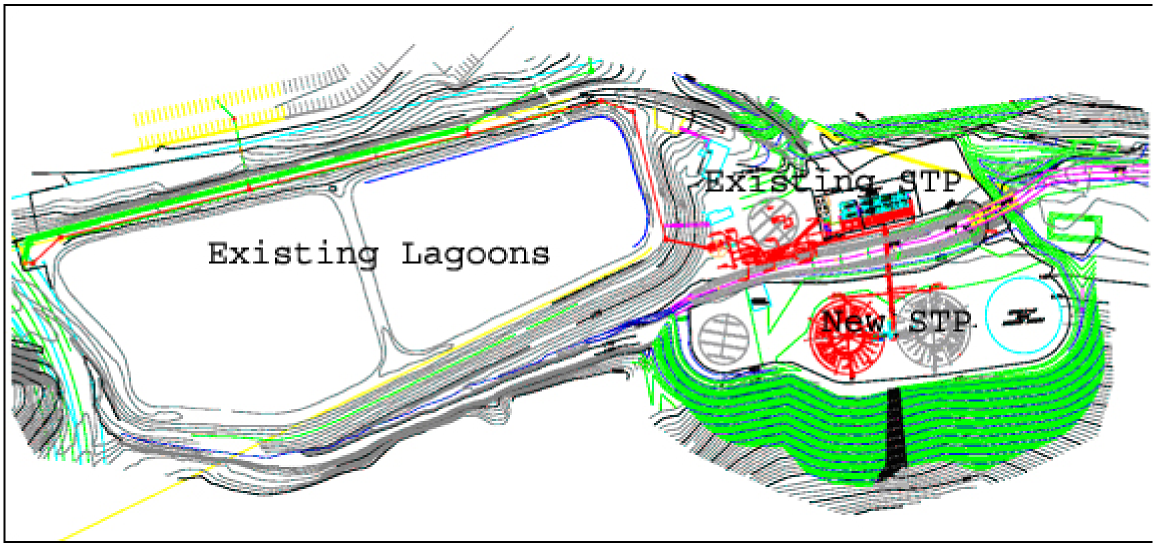

Figure 3-3. Location of the new STP.

The new STP will include: (1) an automatic bar screen for primary screening (removal of large solids); (2) equalization basins with one million gallon capacity for surge control (smooth out flow into the STP); (3) two - 750,000 gallon per day activated sludge treatment plants with anaerobic, anoxic and oxic treatment, clarification and digestion of waste sludge (for solids, organics, and nutrient removal); (4) two – 750,000 gallon per day polishing filters (for final solids removal); (5) ultraviolet (UV) disinfection; and (6) aeration of the final effluent. Chlorination and dechlorination units have also been installed after the polishing filters but will be used only in case of emergencies (operational problems with the UV disinfection system). The new plant is designed to allow for future expansion of the facility through the construction of an additional 500,000 gallon equalization basin, a 750,000 gallon per day activated sludge treatment plant, and a 750,000 gallon per day polishing filter. When completed in 2003, the new plant will have a permitted capacity of 1,500,000 gallons per day and chlorination STP will be eliminated. The plant could be expanded to a capacity of 2,000,000 gallons per day if the expansion units described above are constructed. Sludge from the facility will be hauled and disposed of at an independent sludge disposal site. Figure 3-4 is a schematic of the new STP with future expansions included.

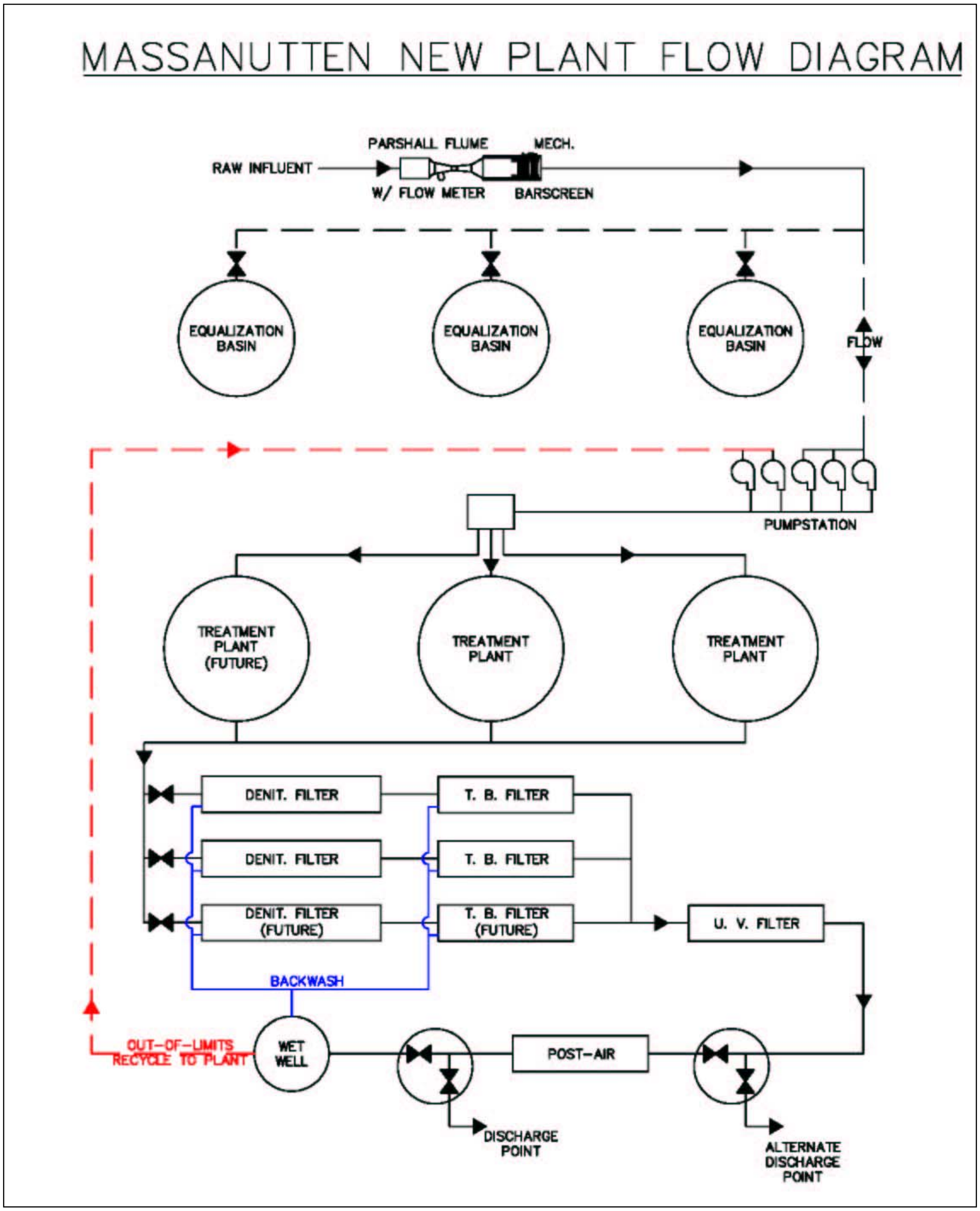

Figure 3-4. Schematic of the new STP.

The new facility is permitted to discharge 1,500,000 gallons per day (1.5 MGD) of wastewater to Quail Run with the effluent standards shown in Table 3-3 (same as in existing permit except that the permitted flow is increased).

Table 3-3. Permitted effluent standards for new STP (1.5 and 2.0 MGD).

Permitted Effluent Characteristics	Monthly Average	Weekly Average	Minimum	Maximum
Fecal Coliform Bacteria				200/100mL
BOD_5 (Biochemical Oxygen Demand)	10 mg/L	15 mg/L		
Total Suspended Solids	30 mg/L	45 mg/L		
Ammonia	2.6 mg/L	2.6 mg/L		
Dissolved Oxygen			7.5 mg/L	
pH (standard units)			6.5	9.5
Total Residual Chlorine	0.01 mg/L*	0.01 mg/L*		
Di-2-Ethylhexyl Phthalate	64.3 μg/L	64.3 μg/L		
Total Cyanide	7.8 μg/L	7.8 μg/L		
Total Nitrogen	No limits; 1/quarter, 24 h composite sample required			
Total Phosphorus	No limits; 1/quarter, 24 h composite sample required			

* Emergency conditions.

Growth in the Massanutten Public Service Corporation area is expected to occur both within the existing service area and in 30 land parcels currently being reviewed for certification into the Massanutten Public Service Corporation service area. The expected uses of these properties are comparable to current development in the Massanutten area. The new development will include single and multi-family residential units (including time-share units), commercial uses, and open spaces. The total number of potential connections in the new areas is estimated to be approximately 1,904. It is expected that the new area will be developed over the next 10 to 15 years, at which time the new STP will serve almost 4000 residences and timeshares.

3.7. Stream Flow Data

There are no flow monitoring stations located on Quail Run. The only flow estimates available are those for a few specific days during which the VADEQ was conducting special water quality monitoring studies. The 7-day duration, 10-year recurrence interval low flow for Quail Run at the Massanutten Public Service Corporation sewage treatment plant (STP) outfall point has been defined as 0.045 cfs for permitting purposes. During extreme low flow conditions, such as those that occurred during the summer of 2002, the effluent from the Massanutten Public Service Corporation STP is the source of most of the flow in Quail Run downstream of the STP outfall. During these extreme low flow conditions, Quail Run has been reported to go dry downstream of the STP outfall when the STP discharge is halted.

3.8. Water Quality Data

3.8.1. Benthic Macro-invertebrates

Biological monitoring has been performed by VADEQ in Quail Run from October 1996 to present at the benthic monitoring stations displayed in Figure 3-5. The biological monitoring is supplemented by ambient water quality monitoring sites and special study sites. Recent VADEQ sites include (the last three digits indicate the location of each monitoring site in miles upstream of the confluence of Quail Run and Boones Run):

Ambient Monitoring Sites (chemical and physical parameters)

- QAL004.30 – downstream of STP
- QAL005.29 – upstream of STP

Massanutten STP discharge (chemical and physical parameters)

- QAL005.07

Benthic Monitoring Sites

- QAL004.30 – downstream of STP
- QAL005.04 – just below STP
- QAL005.09 – upstream of STP

Diurnal DO Monitoring Sites (special studies, chemical and physical parameters)

- QAL004.30 – corresponds with downstream ambient site
- QAL004.82 – maximum DO SAG point, 0.25 miles below STP discharge

Biological monitoring consisted of benthic macro-invertebrate sampling and habitat assessments conducted one or two times per year. Two or more "moderately impaired" benthic ratings during the 5-yr assessment period used for the 1998 303(d) assessment resulted in a portion of Quail Run being assessed as not supporting of the Aquatic Life designated use. VADEQ listed point source pollution from the Massanutten STP as the probable cause of the benthic impairment (VADEQ, 2002).

The Rapid Bioassessment Protocol II (RBP II) is the index used to assess compliance with the general standard in Virginia. This protocol compares the conditions of a target stream to those of an unimpaired reference stream segment. A segment on Strait Creek (STC000.72) was used as the reference for all samples taken on Quail Run. Of the seven assessments performed between October 1996 and May 2002 at QAL005.04, three received a rating of "moderately impaired," and four samples received a "severely impaired" rating, as shown in Table 3-4. The enumeration of the benthic macro-invertebrates within each sample was conducted at the species level and used to calculate a variety of different metrics used in the valuation of the RBP II and MAIS biological indices. The component metrics and RBP II and MAIS indices for each sampling date are presented in Tables 3-4 and 3-5, respectively, for the benthic station immediately downstream of the Massanutten STP outfall (QAL005.04). These results were used both for the 303(d) assessment and in determining the dominant pollutant stressor responsible for the benthic community impairment, as will be discussed in Chapter 4.

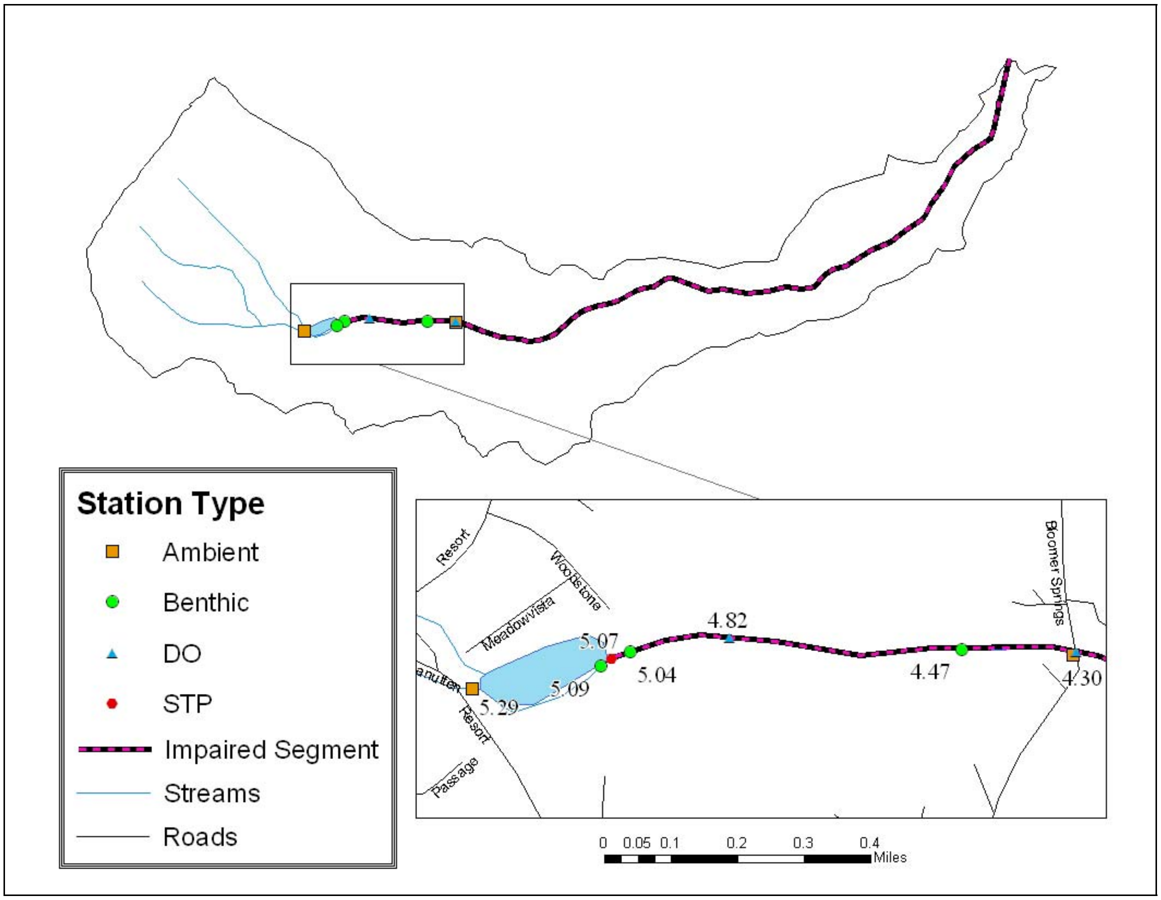

Figure 3-5. Location of Quail Run water quality monitoring stations.

Table 3-4. RBP II scores for Quail Run (QAL005.04).

RBP II (Scores calculated against a reference watershed.)

Sample Date	10/31/96	5/6/97	10/19/98	6/1/99	10/19/99	5/11/00	10/20/00
Samp_ID	701	810	1284	1389	2747	2808	2868
a. RBP II Metric Values							
Taxa Richness	8	4	9	8	10	5	4
MFBI	8.03	6.89	5.85	6.01	5.79	6.27	7.29
SC/CF	2.00	1.00	3.00	0.00	1.00	0.00	0.00
EPT/Chi Abund	0.05	0.00	0.14	0.01	0.00	0.00	0.00
% Dominant	55.00	72.73	43.75	84.06	46.53	74.07	45.18
Dominant Species	Planariidae	Chironomida	Planariidae	Simuliidae	Planariidae	Simuliidae	Planariidae
EPT Index	1	0	1	1	0	0	0
Comm. Loss Index	1.63	4.50	1.78	2.00	1.40	3.40	4.00
SH/Tot	0.00	0.00	0.00	0.00	0.00	0.00	0.00
b. Reference Metric Values							
Station_ID	STC004.27	STC004.27	STC004.27	STC004.27	STC004.27	STC004.27	STC004.27
Reference Sample Date	10/17/96	5/21/97	10/28/98	5/17/99	10/13/99	5/4/00	10/13/00
Reference Sample_ID	704	816	1294	1435	2755	2813	2874
Taxa Richness	16	19	19	18	21	20	19
MFBI	3.78	3.36	3.22	3.79	3.64	4.18	3.61
SC/CF	0.27	0.35	0.37	2.77	3.90	1.19	1.95
EPT/Chi Abund	12.12	15.95	24.78	4.50	18.65	3.27	15.66
% Dominant	32.80	21.43	22.49	20.66	25.23	17.32	25.23
EPT Index	8	13	13	11	10	12	12
Comm. Loss Index							
SH/Tot	7.20	9.29	28.40	16.53	15.32	11.02	5.41
Reference Biological Score	44	46	46	46	46	48	46
c. RBP II Metric Ratios							
Taxa Richness	50.0	21.1	47.4	44.4	47.6	25.0	21.1
MFBI	47.1	48.7	55.0	62.9	62.8	66.7	49.6
SC/CF	750.0	289.2	815.7	0.1	25.6	0.0	0.0
EPT/Chi Abund	0.4	0.0	0.6	0.3	0.0	0.0	0.0
% Dominant	55.0	72.7	43.8	84.1	46.5	74.1	45.2
EPT Index	12.5	0.0	7.7	9.1	0.0	0.0	0.0
Comm. Loss Index	1.63	4.50	1.78	2.00	1.40	3.40	4.00
SH/Tot	0.0	0.0	0.0	0.0	0.0	0.0	0.0
d. RBP II Metric Scores							
Taxa Richness	2	0	2	2	2	0	0
MFBI	0	0	2	2	2	2	0
SC/CF	6	6	6	0	2	0	0
EPT/Chi Abund	0	0	0	0	0	0	0
% Dominant	0	0	0	0	0	0	0
EPT Index	0	0	0	0	0	0	0
Comm. Loss Index	2	0	2	2	4	2	0
SH/Tot	0	0	0	0	0	0	0
Total RBP II Score	10	6	12	6	10	4	0
% of Reference	22.73	13.04	26.09	13.04	21.74	8.33	0.00
RBP II Assessment	**Moderate**	**Severe**	**Moderate**	**Severe**	**Moderate**	**Severe**	**Severe**

The Macroinvertebrate Aggregated Index for Streams (MAIS) is a secondary index whose metrics are also calculated by VADEQ, but it is only used as a supplemental indicator of stream quality. Individual MAIS metrics are rated against a fixed scale rather than against those of a reference watershed, as in the

RBP II index. The various metrics, some of which duplicate those in the RBP II, along with their scores and final ratings are given for each sample in Table 3-5.

Table 3-5. MAIS assessment results for Quail Run (QAL005.04).

MAIS (Scores calculated against a fixed scale. Values indicating the best conditions are shown at the far right.)

a. MAIS Metric Values

Sample Date	10/31/96	5/6/97	10/19/98	6/1/99	10/19/99	5/11/00	10/20/00	**Best Score or Category**
% 5 Dominant	58.82	49.34	82.46	86.84	65.29	65.77	58.27	<79.13
MFBI	3.24	3.74	3.78	3.17	3.79	3.64	4.18	<4.22
% Haptobenthos	73.11	78.95	91.23	60.53	87.60	85.59	77.17	>83.26
EPT Index	13	14	8	9	11	10	12	>7
# Mayfly Taxa	4	4	4	4	4	3	5	>3
% Mayfly Abundance	49.58	25.66	58.77	68.42	31.40	24.32	28.35	>17.52
Simpson's Diversity Index	0.91	0.94	0.82	0.78	0.90	0.89	0.92	>0.823
# Intolerant Taxa	17	21	13	10	15	17	16	>9
% Scraper Abundance	31.09	17.76	6.14	29.82	25.62	53.15	22.83	>10.7

b. MAIS Scores

% 5 Dominant	2	2	1	1	2	2	2	2
MFBI	2	2	2	2	2	2	2	2
% Haptobenthos	1	1	2	1	2	2	1	2
EPT Index	2	2	2	2	2	2	2	2
# Mayfly Taxa	2	2	2	2	2	1	2	2
% Mayfly Abundance	2	2	2	2	2	2	2	2
Simpson's Diversity Index	2	2	1	1	2	2	2	2
# Intolerant Taxa	2	2	2	2	2	2	2	2
% Scraper Abundance	2	2	1	2	2	2	2	2
Total MAIS Score	17	17	15	15	18	17	17	**18**
MAIS Assessment	**Very Good**	**Very Good**	**Good**	**Good**	**Very Good**	**Very Good**	**Very Good**	**Best**

A qualitative analysis of various habitat parameters was conducted in conjunction with each biological sampling. The values for each of the 10 parameters listed in Table 3-6 ranged from a maximum score of 20 (indicating the most desirable condition), and a minimum score of 0 (indicating the poorest habitat conditions).

Table 3-6. Habitat Evaluation scores for Quail Run.

Quail Run (QAL005.04)

Habitat Evaluation Date	10/31/96	5/6/97	10/19/98	6/1/99	10/19/99	5/11/00	10/20/00
HabSampID	QAL609	QAL719	QAL1132	QAL1210	QAL2447	QAL2507	QAL2566
ALTER	10	16	18	12	13	18	18
BANKS	8	16	17	14	12	20	13
BANKVEG	10	16	15	13	15	20	15
EMBED	10	10	18	11	14	10	5
FLOW	16	16	18	18	19	18	16
RIFFLES	14	16	18	15	17	16	16
RIPVEG	14	20	12	9	13	19	8
SEDIMENT	10	12	18	16	15	18	13
SUBSTRATE	12	10	13	12	14	18	14
VELOCITY	14	14	15	14	14	16	14
Total Habitat Score	118	146	162	134	146	173	132

Table notation: ALTER = channel alterations; BANKS = bank stability; BANKVEG = bank vegetation; EMBED = embeddedness; FLOW = flow quantity; RIFFLES = presence of riffles; RIPVEG = riparian vegetation; SEDIMENT = abundance of bottom sediment; SUBSTRATE = availability of firm, clean stream bottom surfaces; VELOCITY = velocity of flow.

Results for the two other benthic monitoring stations on Quail Run are shown in Table 3-7. Station QAL004.30 is located approximately 4,000 ft downstream of the STP discharge point. As indicated in Table 3-7, the stream is still benthically impaired at this point, although the rating is better than it is immediately downstream of the STP outfall at station QAL005.04. At the benthic monitoring station upstream of the STP outfall, QAL005.09, the stream is also slightly impaired, however it is much better than the two stations below the STP outfall. The moderate ratings at QAL005.09 are believed to be largely due to extremely low flow conditions in Quail Run during 1999 and 2000. Based on flow records for the South Fork of the Shenadoah River, the low flow conditions in 1999 and 2000 would only be expected to occur once in 11 and 5 years respectively. It is believed that these extreme low flow conditions, combined with VADEQ reported leakage from the lagoons immediately upstream of the QAL005.09 benthic monitoring site, caused the stream to be impaired at this point. Upstream of the lagoons, where there was no lagoon leakage, Quail Run was most likely unimpaired.

Table 3-7 RBP II scores for Quail Run benthic stations.

Monitoring Station	Monitoring Date								
	Oct-96	May-97	Oct-98	Jun-99	Oct-99	May-00	Oct-00	Oct-01	May-02
QAL004.30	Moderate	Moderate	Moderate	Moderate	Moderate	Severe	Moderate	Slight	Severe
QAL005.04	Moderate	Severe	Moderate	Severe	Moderate	Severe	Severe		
QAL005.09	Slight	Slight	Moderate	Moderate	Moderate	Moderate	Slight	Slight	

CHAPTER 4: BENTHIC STRESSOR ANALYSIS

4.1. Introduction

TMDLs must be developed for a specific pollutant. Because a benthic impairment is based on a biological inventory, rather than on physical or chemical water quality standards, the pollutant is not implicitly identified in the assessment. The process outlined in EPA's Stressor Identification Guidance Document (USEPA, 2000) was used to identify the critical stressors for Quail Run. A list of candidate causes was developed from published literature and stakeholder input. Chemical and physical monitoring data provided additional evidence to support or eliminate the potential candidate causes. Logical pathways were explored between observed effects in the benthic community, potential stressors, and intermediate steps or interactions that would be consistent in establishing a cause and effect relationship with each candidate cause. The common candidate benthic stressors are sediment, organic matter, pH, toxics, nutrients, suspended solids, and temperature. Each of these is considered in the following sections.

In the following discussion, VADEQ ambient monitoring data were compared between a site below the Massanutten STP (QAL004.30) and a site upstream of the STP (QAL005.29), to assess both the level of measurements and evaluate the influence from the encompassed Massanutten STP. Ambient water quality monitoring station QAL005.29 was selected as the unimpaired reference site because it is well upstream of the STP outfall and the leaking lagoon that was believed responsible for the recent benthic impairment at QAL005.09. As stated previously, it is believed that the benthic impairment at QAL005.09 is the result of recent drought conditions and leakage from the STP lagoons upstream of the station. Thus, Quail Run should not be benthically impaired upstream of the STP lagoons and ambient water quality monitoring station QAL005.29 is an appropriate unimpaired reference site for the impaired portion of Quail Run, which is represented using ambient water quality data from QAL004.30. Locations of the two stations in relation to the STP are shown in Figure 3-5. If measurements for a given pollutant at both stations were within a normal range of values, that pollutant (stressor) was eliminated from further consideration. Where levels of a given stressor were above normal, additional information was sought to help explain levels that could contribute to stress on the benthic community. Additional data considered in this analysis came from the Massanutten STP's monthly Discharge Monitoring Reports (DMRs), submitted to VADEQ as part of its permit requirements.

4.2. Eliminated Stressors

4.2.1. Suspended Solids

In-stream total suspended solids (TSS) (Figure 4-1) and turbidity measurements (Figure 4-2) were all at low levels and well within the range of values reported at the reference site. Total suspended solids and turbidity were consequently eliminated as a source of the impairment. As indicated in Figure 4-3, the existing STP periodically violates its suspended solids permit limit of 30 mg/L, but there is no indication that this contributes to the impairment.

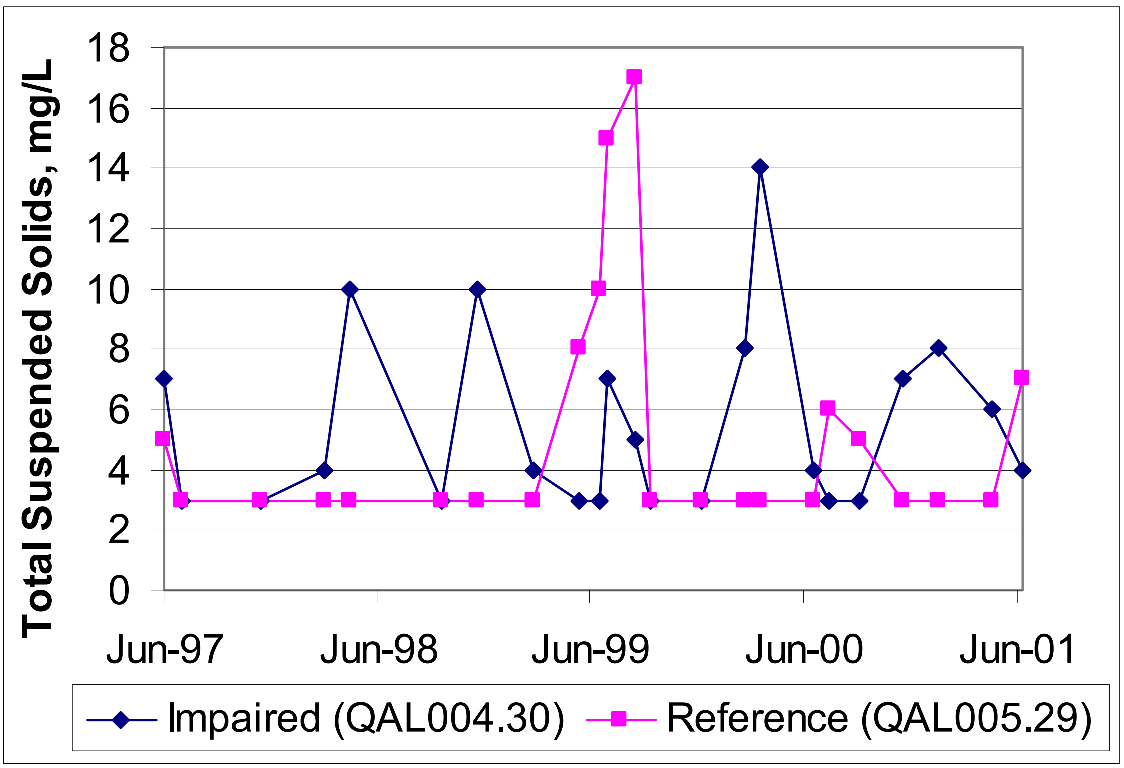

Figure 4-1. VADEQ suspended solids concentration in Quail Run.

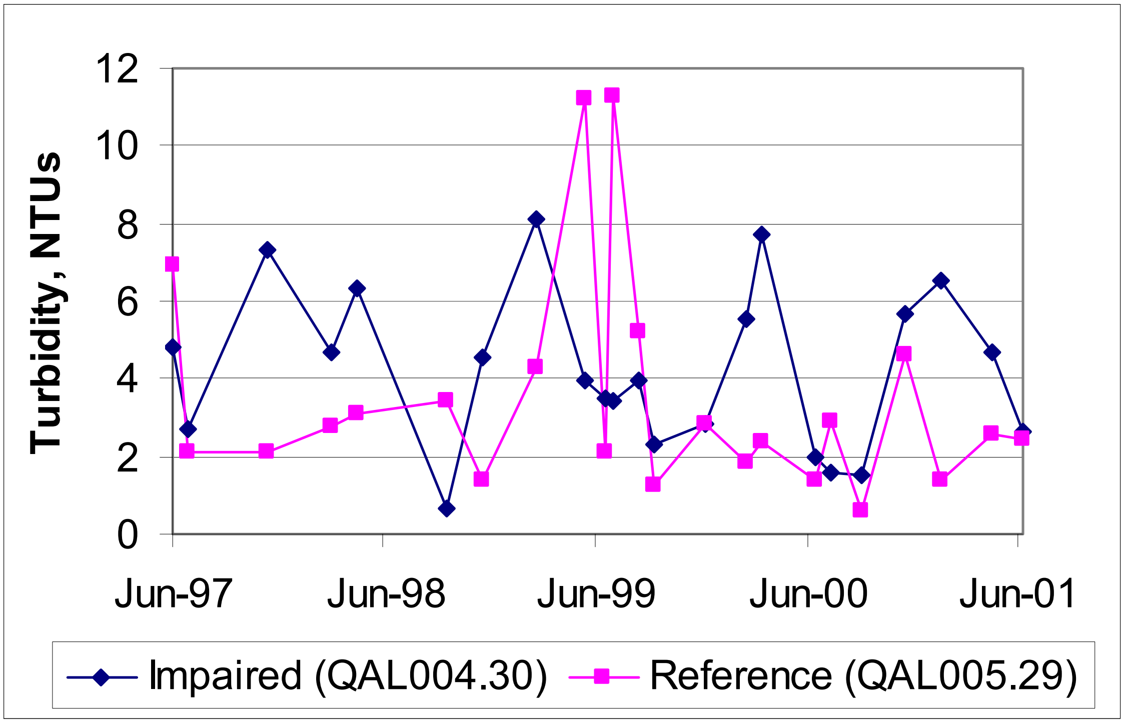

Figure 4-2. VADEQ turbidity data for Quail Run.

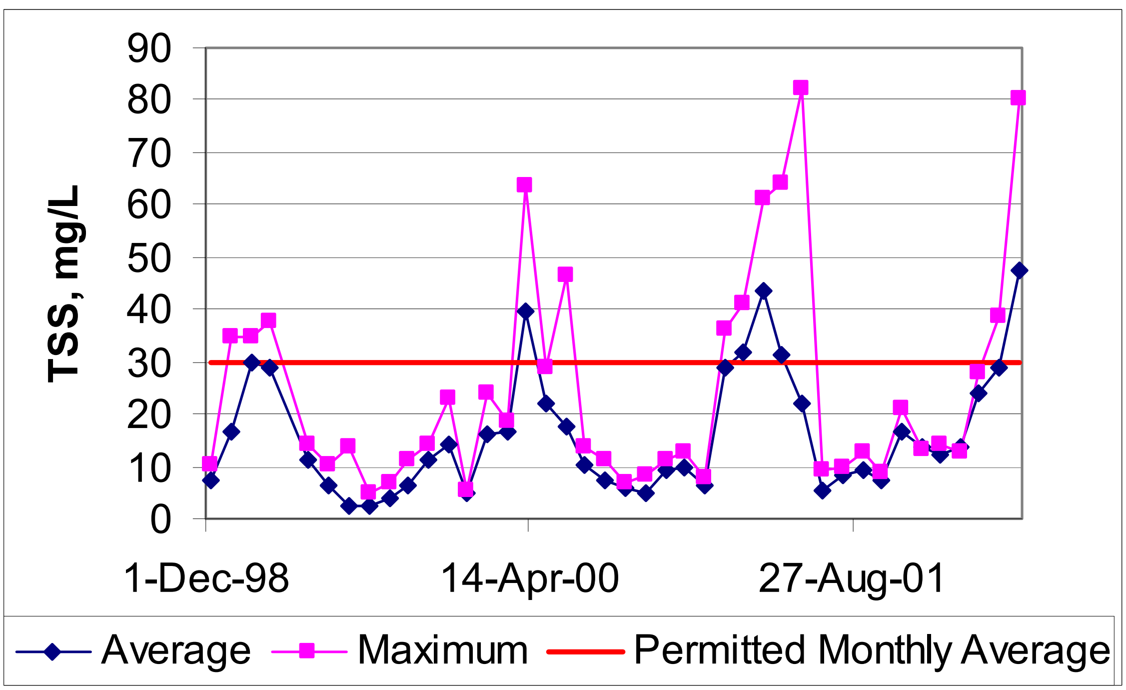

Figure 4-3. Massanutten STP effluent - monthly DMR TSS Data.

4.2.2. Temperature

As shown in Figure 4-4, differences in stream water temperature between the upstream reference site and the downstream impaired site were minimal, indicating that the STP has little impact on stream temperature. In addition, the stream temperature never exceeded the maximum allowable temperature standard of 31°C for Class IV waters. Temperature does not appear to be a stressor.

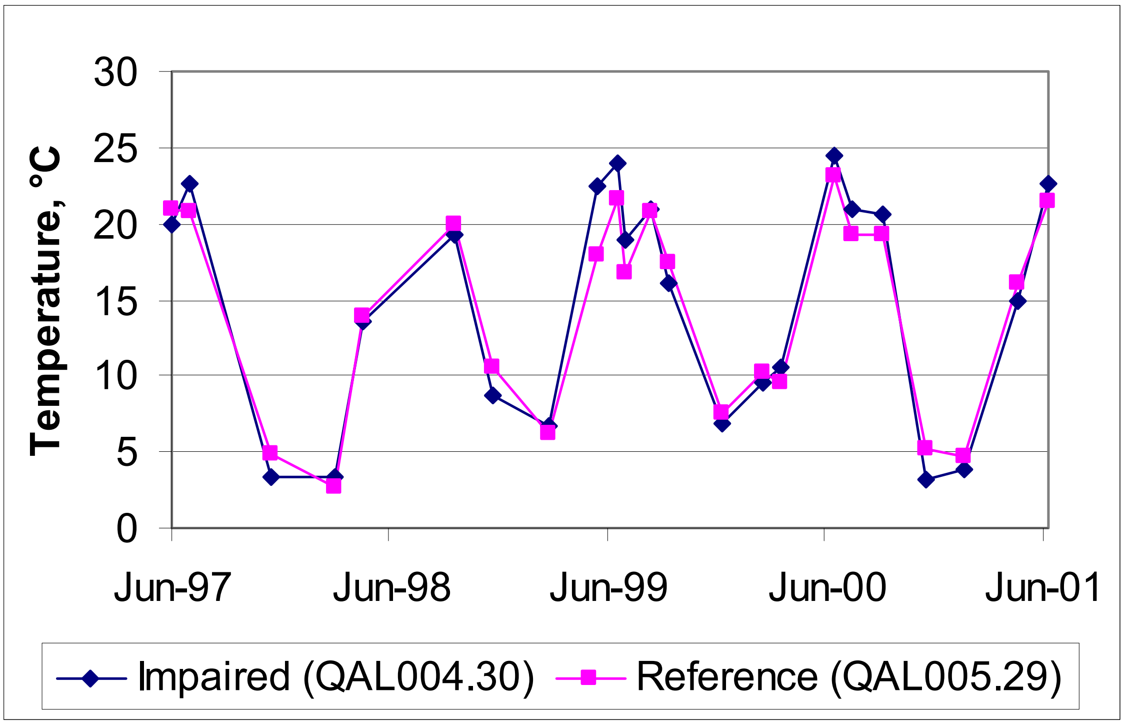

Figure 4-4. Water temperature in Quail Run.

4.2.3. pH

All field measurements of in-stream pH values fall between the recommended limits of 6 to 9, as shown in Figure 4-5. Alkalinity concentrations are also within a normal range for areas within the Ridge and Valley physiographic region as shown in Figure 4-6, with the STP contributing to slightly lower alkalinity downstream. pH is not a stressor.

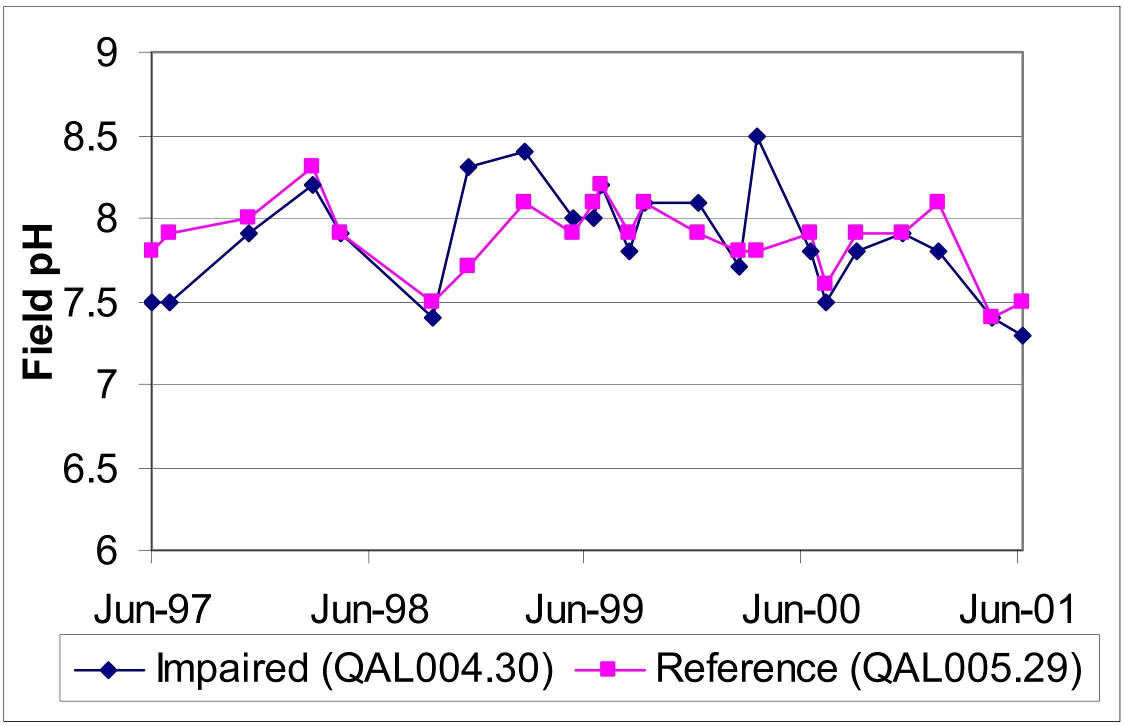

Figure 4-5. Field pH data for Quail Run samples.

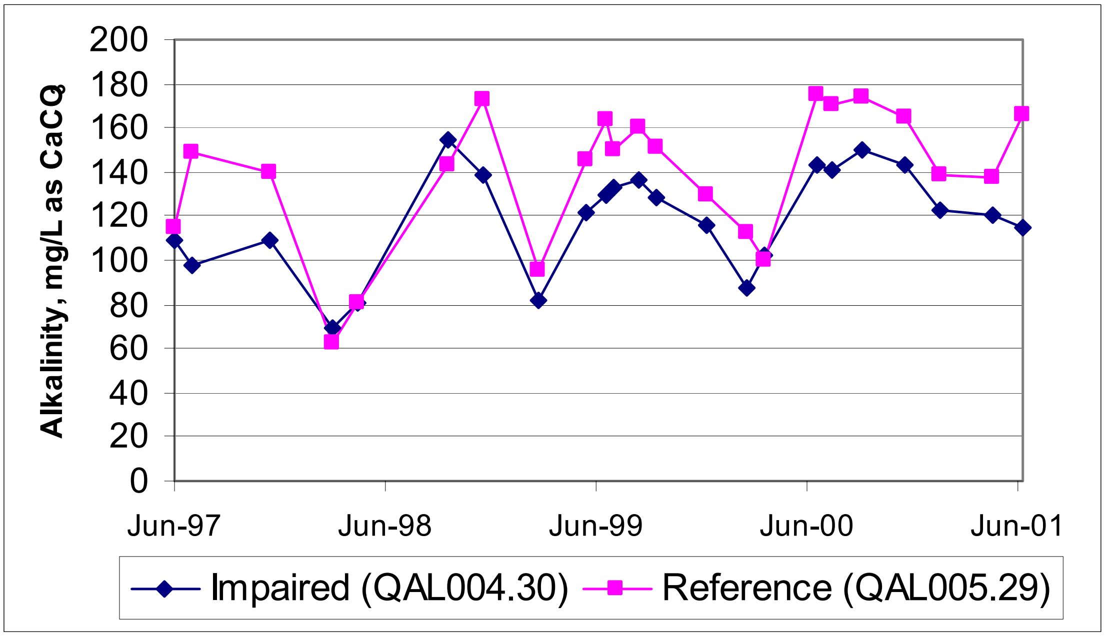

Figure 4-6. Alkalinity concentration in Quail Run.

4.2.4. Dissolved Oxygen (DO)

Dissolved Oxygen concentrations in Class IV waters, which include Quail Run, are expected to meet the minimum standard concentration of 5.0 mg/L. All monthly VADEQ samples greatly exceeded this minimum (Figure 4-7), and daily STP DO values are well above its permitted minimum DO of 7.5 mg/L (Figure 4-8). Based on available ambient monitoring data, dissolved oxygen does not appear to be a stressor.

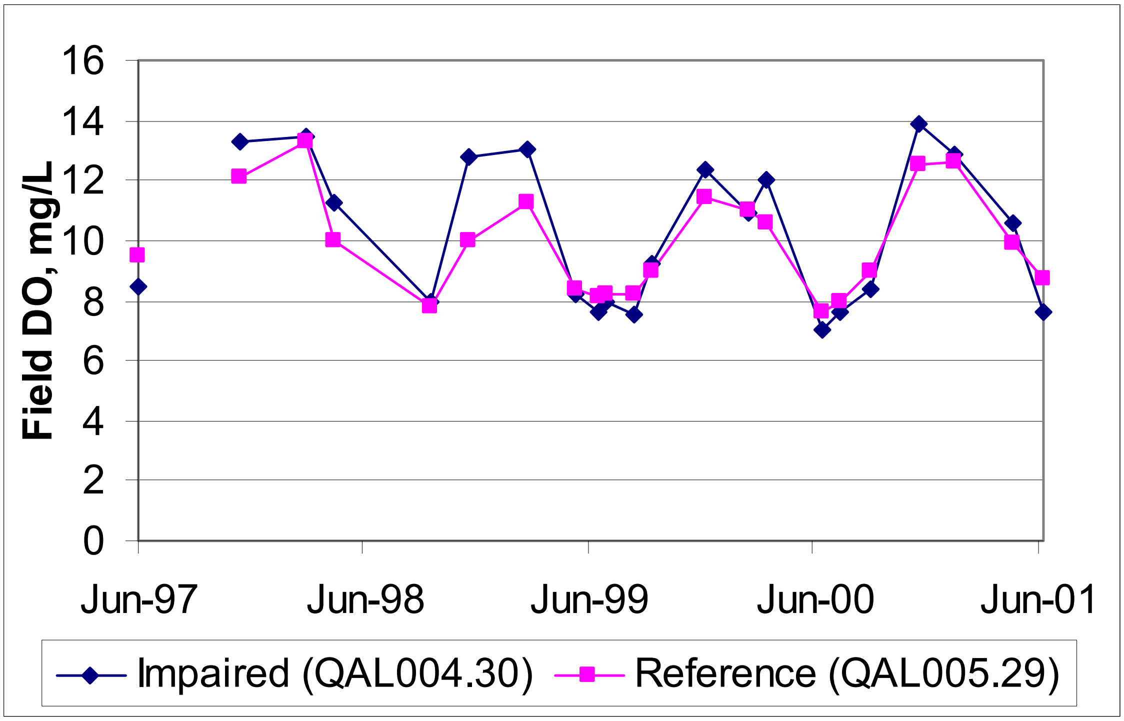

Figure 4-7. DO concentration in Quail Run.

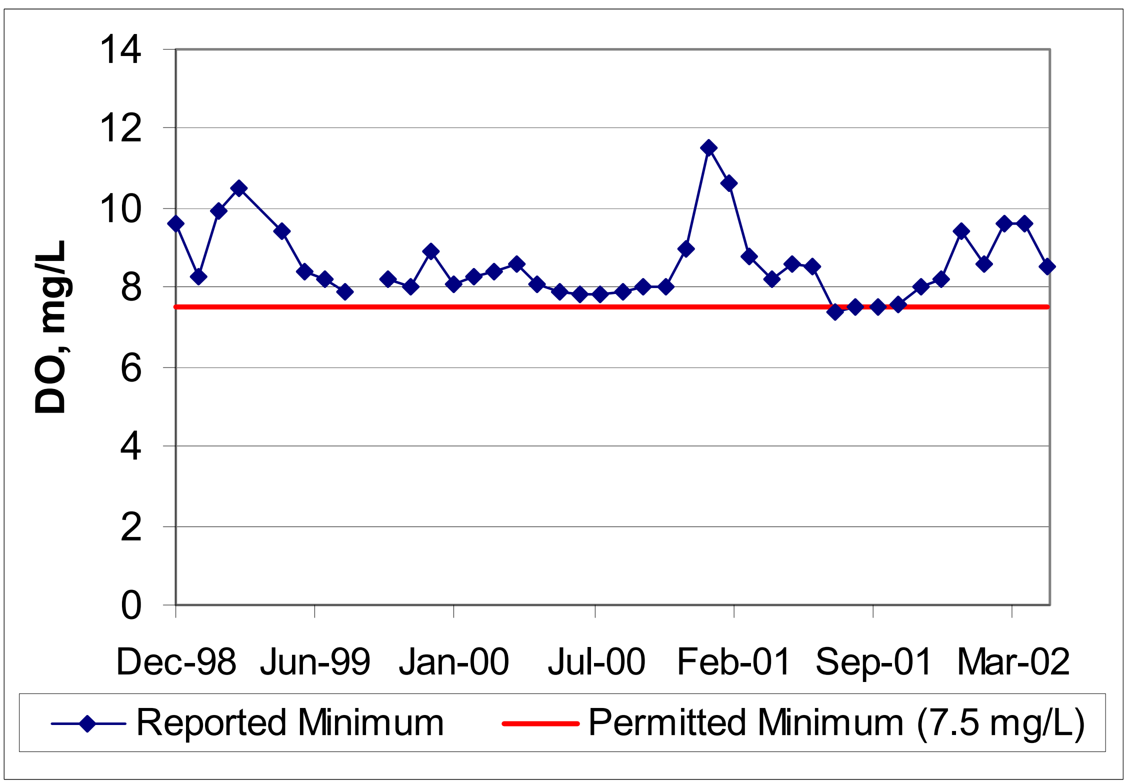

Figure 4-8. Massanutten STP effluent - Daily Minimum DO.

4.2.5. Chlorides

Increasing levels of chloride have been noted downstream from the STP, as shown in Figure 4-9. Although these are well below the chronic Aquatic Life criteria (230 mg/L), they may be accompanied by free chlorine residuals at levels exceeding their criterion (0.01 mg/L). Additionally, chlorination may result in the formation of other toxic compounds as by-products. Anecdotal evidence has indicated operational problems at the STP during periods of breakpoint chlorination. Chlorides do not appear to be a stressor, but chlorine and chlorination by-products may be and will be discussed later in the toxics section of the stressor analysis.

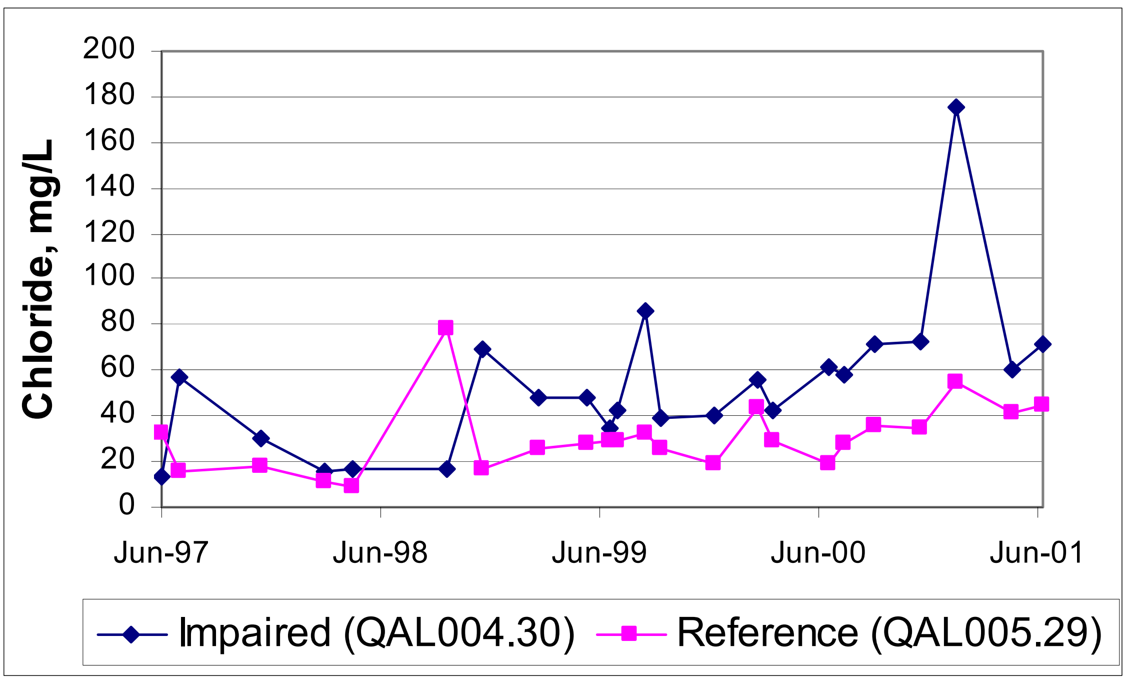

Figure 4-9. Chloride concentration in Quail Run.

4.3. Possible Stressors

4.3.1. Organic Matter

Five-day biochemical oxygen demand (BOD_5) and chemical oxygen demand (COD) are used to measure organic matter loadings to streams. They have been measured at monitoring stations upstream and downstream of the

STP, and show increasing levels downstream (Figures 4-10 and 4-11). The Modified Family Biotic Index (MFBI) metric (Table 3-4) has been at a high level during all sampling periods indicating organic sources of pollution. The Massanutten STP effluent BOD_5 also appears to frequently exceed its 10 mg/L monthly average BOD_5 permit limits (Figure 4-12). Organic matter seems to be a stressor, however the expected impact of decreased DO concentrations has not been observed (Figure 4-7). Organic matter, therefore, is a possible stressor.

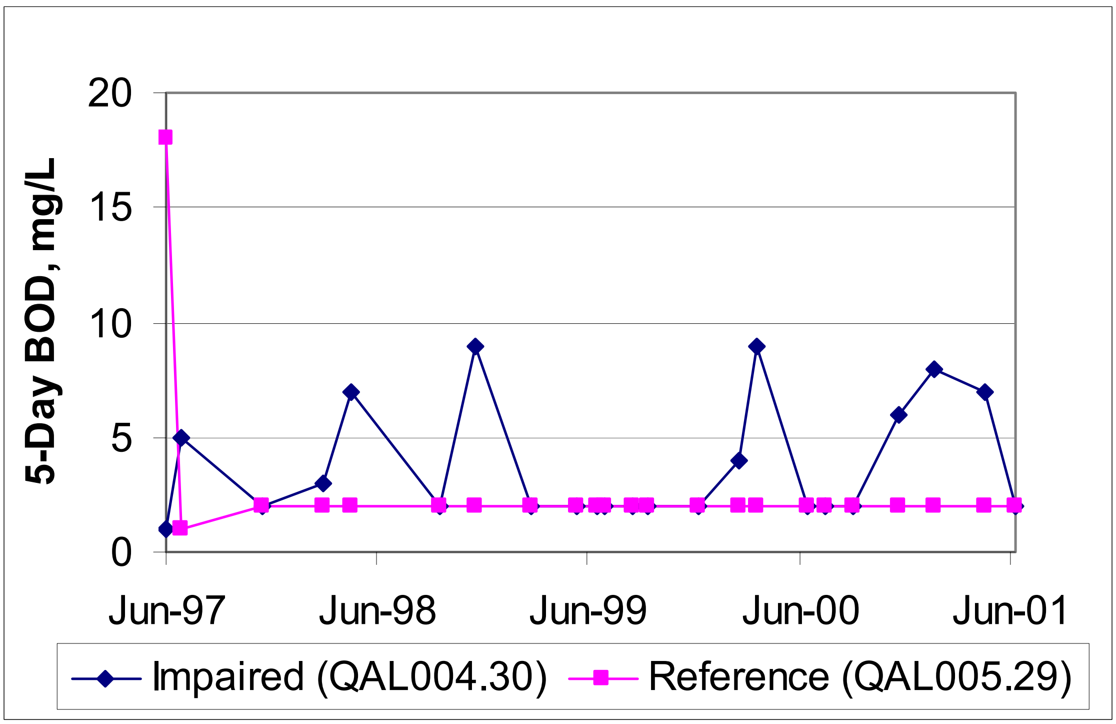

Figure 4-10. BOD_5 concentration in Quail Run.

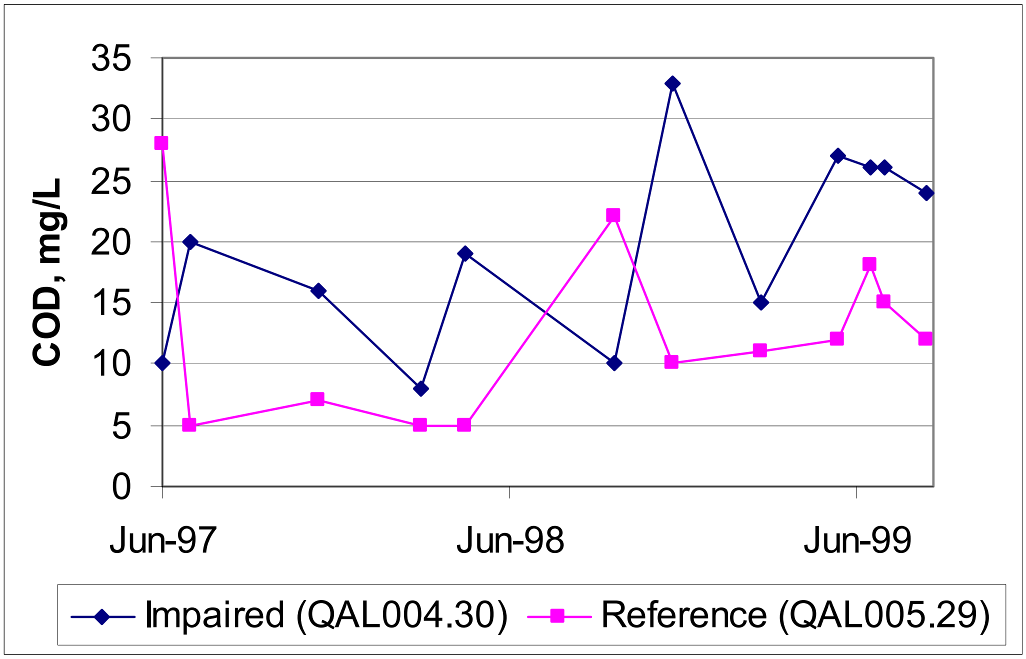

Figure 4-11. COD concentration in Quail Run.

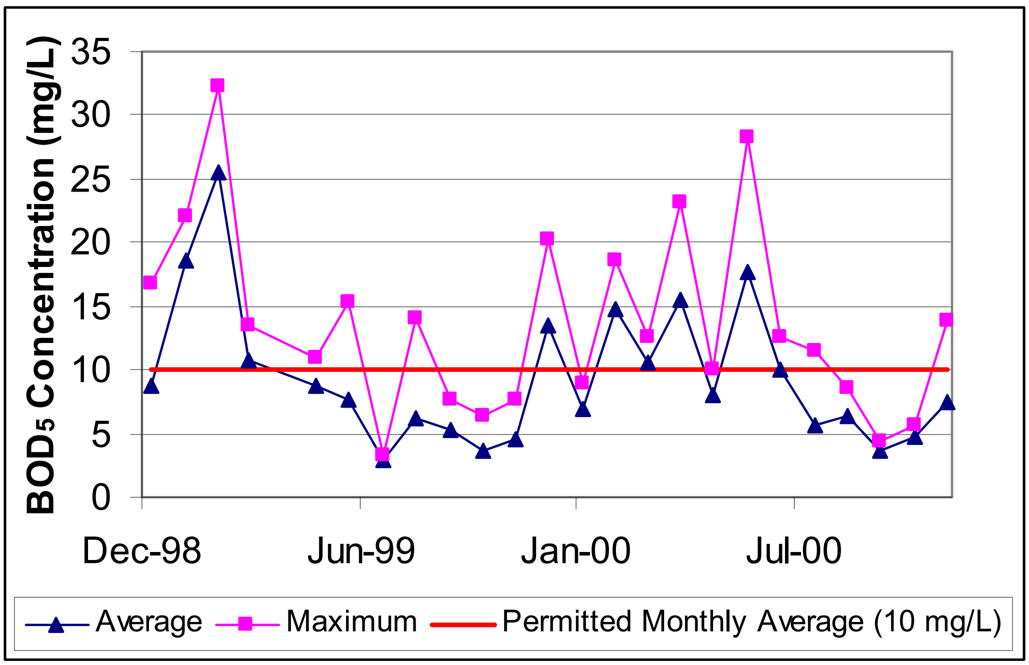

Figure 4-12. Massanutten STP effluent - monthly DMR BOD_5.

4.3.2. Sediment

The percent haptobenthos metric scores (%haptobenthos in Table 3-5), which indicate increased bedload sediment, have been decreasing, even though Habitat Evaluation scores (Table 3-6) for substrate remain high. The embeddedness score dropped precipitously on the 10/02/01 sampling date, also indicating increasing sediment levels. Construction on the new STP began the month prior to the embeddedness score drop. Continuous development in the watershed, primarily due to the Massanutten development, is a likely source of increased sediment loadings to Quail Run. More recently, clearing of the forested riparian zone downstream of the STP, STP construction, and the channelization of Quail Run in the immediate vicinity of the STP have likely increased sediment loadings to the stream dramatically, but water quality data are not available to document it. These sources are temporary sources of elevated sediment loadings and it is impossible to conclude from the available data whether sediment is a definite stressor.

4.4. Most Probable Stressors

Multiple stressors appear to be affecting the benthic community in Quail Run, including nutrients, ammonia, chlorine, and chlorination by-products.

4.4.1. Nutrients

Concentrations of both nitrogen (N) and phosphorus (P) are considerably elevated at the downstream site (Figures 4-13 and 4-14). There are currently no specific water quality standards for N and P, but the VADEQ considers concentrations of total phosphorus (TP) greater than 0.2 mg/L to constitute threatened conditions that should be watched more closely. The VADEQ formerly assessed free flowing waters as threatened for phosphorus if greater than 10% of samples exceeded 0.2 mg/L during an assessment period. Due to the EPA and state difference in the definition of threatened watersthat now require 303(d) listing and TMDL development, and the lack of Water Quality Standards for nutrients, VADEQ does not plan to assess waters as threatened due to nutrients for the upcoming 2004 Water Quality Assessment. All data relative to aquatic life use support will be reviewed and considered before a final assessment is made.

Concentrations of TP greater than the 0.2 mg/L threshold have been observed both upstream and downstream of the STP outfall, with more TP threshold exceedances (>0.2 mg/L) reported downstream (Figure 4-14). Fiveyear average concentrations of dissolved N and P are both above levels needed for eutrophic growth. Periodic sampling inspection reports, conducted and prepared by VADEQ, reported STP effluent TP concentrations of 3.0 mg/L and 3.4 mg/L in 1996 and 1998, respectively.

Due to the construction of the new STP and the recent expansion of the Massanutten development and golf course in the area downstream of the existing STP, several thousand feet of formerly meandering and forested riparian zone were, or are, in the process of being cleared. In the immediate vicinity of the STP, the existing stream was straightened and stabilized in places with riprap for approximately 350 ft downstream of the STP outfall as shown in Figures 4-15 and 4-16. Elimination of the forest canopy greatly increased the amount of sunlight reaching the stream channel and is believed to have caused/contributed to the observed increased growth of periphyton (attached algae) in the stream downstream of the STP. Prior to the clearing of the riparian zone and the elimination of the forest canopy, eutrophic periphyton growth was not reported to be a problem.

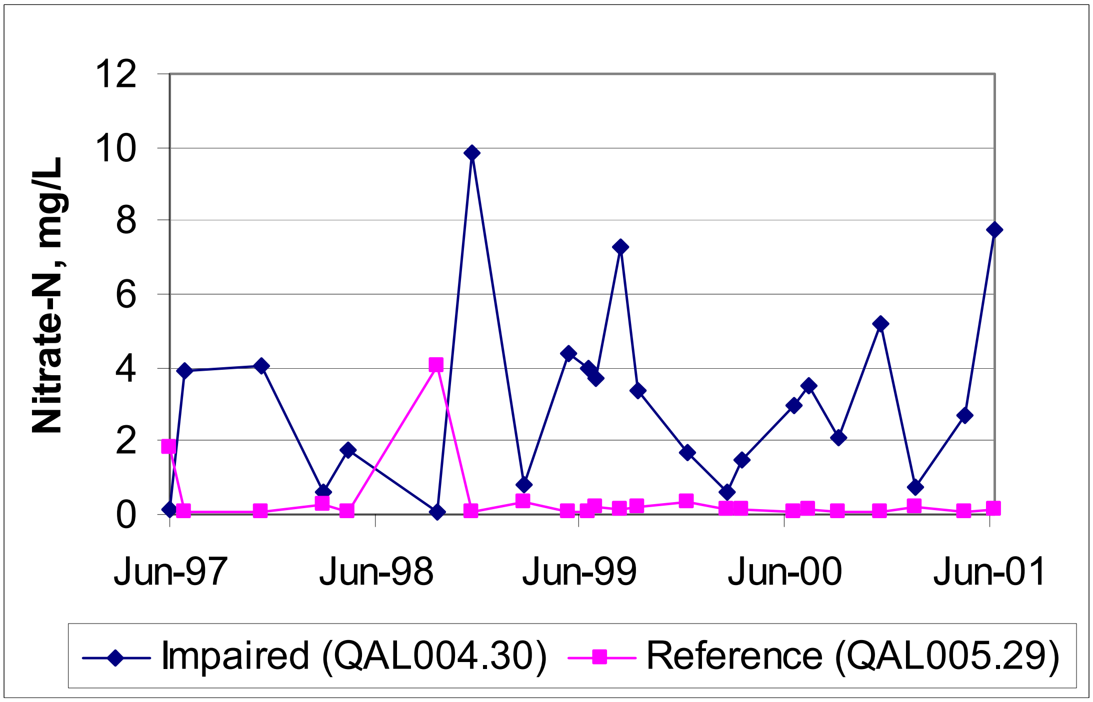

Figure 4-13. Nitrate-N concentration in Quail Run.

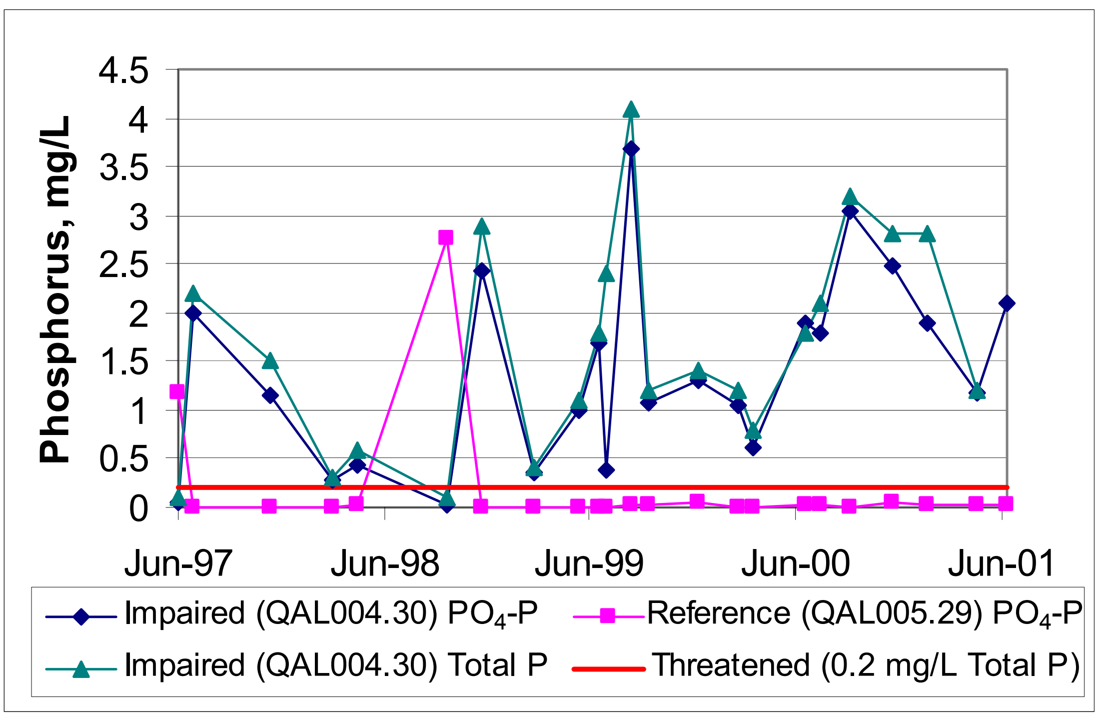

Figure 4-14. Phosphorus concentrations in Quail Run.

Figure 4-15. Channel modifications in the riparian zone due to STP construction.

Figure 4-16. Channel modifications downstream of STP.

Because of concerns about the effects of nutrients on algae growth and dissolved oxygen (DO) levels in the stream, the VADEQ conducted two special diurnal dissolved oxygen monitoring studies (DO Sag Studies) on Quail Run on August 15-16 and September 17-18, 2002. In the diurnal DO studies, continuously recording water quality sensors were placed in the streams and DO, temperature, and other parameters were recorded at 15 minute intervals over a 24-hour period to determine if DO standards were violated during the night when DO levels typically drop to their lowest levels. Both of these studies were conducted during extreme low streamflow conditions approximately equal to or less than the 7-day duration, 10-year return interval flow of 0.045 cfs. Consequently, they represent worst-case conditions. As indicated in Figures 4-17 and 4-18, there is a decrease in dissolved oxygen concentrations downstream of the STP outfall; however, the results of the two studies are somewhat contradictory. Dissolved oxygen measurements at QAL004.82 (the estimated "sag point" for the STP discharge) were much less than the DO standard of 5 mg/L during the August study, as indicated in Figure 4-17, but the stream appears to have recovered 4000 ft downstream at station QAL004.30, which is closer to the impaired benthic monitoring station (QAL004.47). During the September diurnal DO study (Figure 4-18) there were violations of the standard at a new monitoring point, QAL004.96, which was approximately 1000 ft below the STP outfall, but the stream DO levels had recovered at station QAL004.82 (that was a problem in August) and did not violate the 5 mg/L DO standard. One additional point was monitored in the September diurnal DO study, QAL005.09, which was approximately 100 ft upstream of the STP outfall. As indicated in Figure 4.18, DO levels at this point also violated the DO standard during the early morning hours.

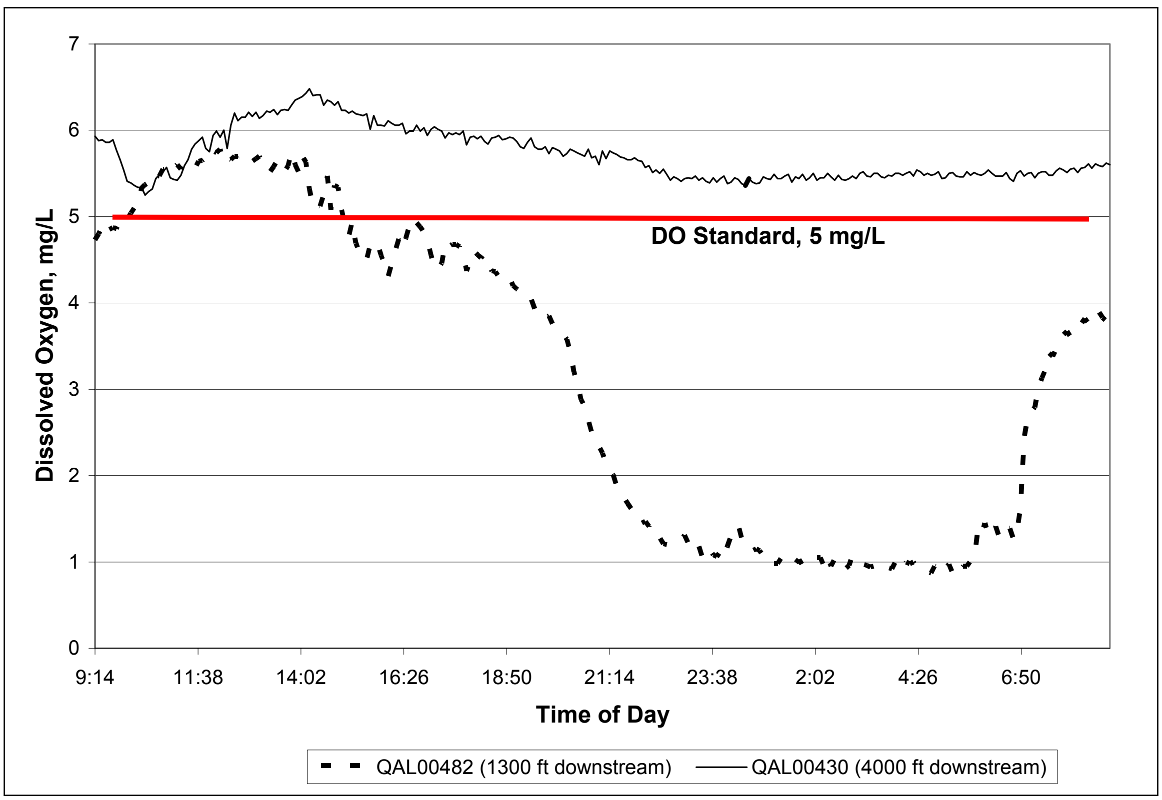

Figure 4-17. VADEQ DO sag study, Aug. 15-16, 2002.

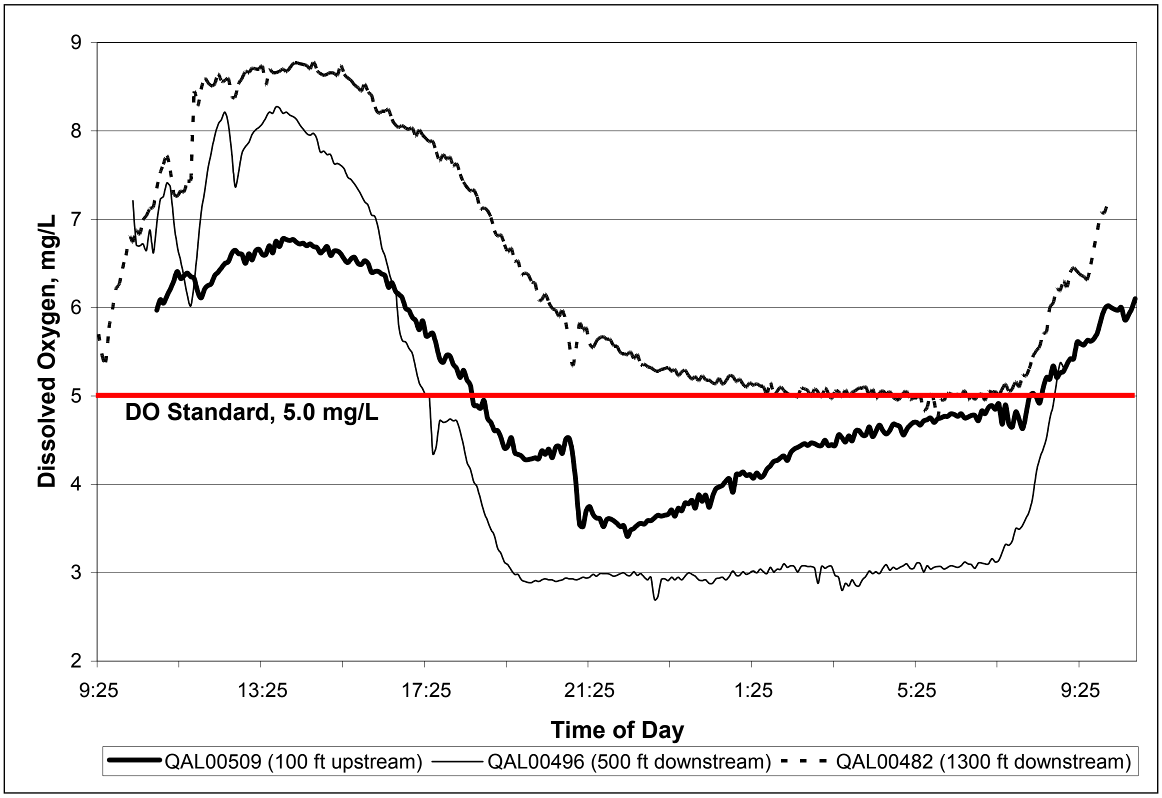

Figure 4-18. VADEQ DO sag study, Sept. 17-18, 2002.

The low DO levels were also possibly due to increased periphyton growth as indicated in the following excerpt from a VADEQ memorandum describing a site inspection on August 22, 2002:

> "I did a stream inspection from 200 feet upstream to 200 feet downstream of the discharge point. The "microbial film" was in fact a thick spyrogyra like algal mat on the stream bottom for the first 75 feet below the receiving stream (% stream bottom coverage = 80 %), and for the next 100 feet or more the algae changed to cladophora like, ropy strings of algae (coverage about = 50%). I did not inspect the stream below the 200 ft point below the discharge. There were also algal mats upstream too. We are assuming they are caused by nutrient leaching from the lagoon berms (waste water leakage has been documented to happen at this facility). The mats were rather different up stream due to the reduced flows. It is likely, in my opinion, in the absence of all this plant life, the night time DO sag would be GREATLY reduced.
>
> While there were minnows in the stream upstream and downstream from the discharge point, there appeared to be many more minnows in the stream upstream of the discharge point.

> In the last two years 350 ft. of the stream inspected had been channelized, denuded, and the stream bank tree's were removed as part of the STP replacement. Because of this the stream bottom gets many times the illumination it was getting formerly, and stream bottom algal growth, particularly below the discharge, has increased dramatically. Because of this large algal biomass standing crop, I believe the night time DO values have dropped dramatically (to ~1 mg/l DO for much of the night). So the DO values speaks to stream shade removal and nutrients, and not to BOD."

In summary, it appears that nutrients are a potential stressor based on the measured nutrient levels, the elevated periphyton levels, and the diurnal DO studies. However, the increased periphyton growth due to modifications of the riparian zone is relatively recent and is not indicative of conditions during the period when the stream was assessed for benthic impairment. In addition, the results of the August and September diurnal DO studies are somewhat contradictory and may also be heavily influenced by sediment loadings due to construction activity during this period. Consequently, they are probably not indicative of conditions during which the stream was assessed for benthic quality. Finally, the long-term ambient water quality data do not indicate that DO is a problem. For these reasons, it is difficult to conclude that nutrients are a stressor.

4.4.2. Toxics

Potential toxics identified during the course of this study that could contribute to the impairment include: ammonia, residual chlorine, chlorination by-products, and pesticides from lawns in the watershed. The ammonia, residual chlorine, and chlorination by-products would be associated with the effluent from the existing STP.

Ammonia

Since the beginning of VADEQ ambient water quality sampling in mid-1997, 4 out of 22 in-stream samples (18%) appear to have exceeded the freshwater chronic standard for ammonia downstream from the STP (Figure 4-19). The chronic standard for ammonia in Figure 4-19 varies with time since ammonia toxicity to aquatic organisms is a function of both temperature and pH. In-stream ammonia concentrations increased greatly between the upstream reference monitoring station (QAL005.29) and the downstream station (QAL004.30), presumably due to the STP discharge. However, the reported monthly DMR ammonia concentrations from samples taken from the STP effluent (Figure 4-20) exceeded the effluent permit only once and do not generally reflect the higher concentrations of ammonia measured at the downstream ambient monitoring station during the overlapping period from January through July 2001. The dates on which the ammonia violations occurred are shown in Table 4.1. Three of the four violations occurred during the winter or early spring when water temperatures are cold and the STP has traditionally experienced problems with its nitrification reactor, which is used to reduce ammonia levels. As stated previously, the STP has a difficult time meeting its permitted ammonia values during cold weather and uses breakpoint chlorination to control the ammonia discharge. The fact that the ammonia violations occurred during cold weather when the nitrification reactor was likely off-line or only marginally effective suggests that the STP is a likely source of the ammonia, even though this is not reflected in the STP DMR reports.

Nonpoint sources were also considered as a possible contributor the exceedances of the in-stream ammonia standard. Agriculture was eliminated as a possible source of ammonia because there is negligible agricultural land in the watershed upstream of the ambient monitoring stations (Figures 2-2 and 3-5). Almost all the agricultural land is located downstream of QAL004.30. Land use upstream of the ambient monitoring stations is either forest or residential/commercial, with turf (lawns and golf courses) being the only likely source of ammonia. Since nonpoint source contributions of ammonia would be expected to be associated with surface runoff events, precipitation patterns were investigated on the day of each violation and for the previous two week period. As shown in Table 4.1, there was little precipitation on the days of the violations and in general low or average precipitation during the previous two week period. The only day of a violation with any precipitation was Dec. 12, 1999, but the 0.12 inches of rainfall that occurred was too small to result in runoff. Looking at the data in Table 4.1, the only violation date with sufficient rainfall to produce runoff during the week before the violation was Dec. 12, 1999, which had 0.75 inches of runoff six days (Dec. 6, 1999) prior to the violation. In general, there was little potential for runoff and nonpoint source contributions for two weeks prior to any of the violation dates.

Fertilizer use was also investigated in the turf areas and particularly the two Massanutten Resort golf courses (Mountain Greens, which is upstream of the STP outfall, and Woodstone Meadows, which is just below the STP outfall) in the Quail Run Watershed. In general, the golf courses are fertilized once per year in September with granular fertilizer and the nitrogen is in the form of urea. This urea would rapidly be converted to ammonia when the urea granules dissolved after the first rain or irrigation event. The resulting ammonia would then be taken up by vegetation or converted to nitrate. This would have occurred long before the ammonia violations in Table 4.1, so golf course fertilization is an unlikely source of the ammonia violations. Fertilizer is used at other times of the year if areas turf areas are being repaired of established, but this use is minor according to the resort greens keeper. Irrigation is not used to apply fertilizer and irrigation is managed to minimize runoff. Figure 4-19 also supports the contention that nonpoint sources are not the problem because ammonia concentrations are very low, with no standards violations upstream (QAL005.29) of the STP, even though there is significant turf and a golf course upstream of this station. Additionally, if the golf courses were contributing to the ammonia violations, one would be more likely to see a spike in nitrate concentrations around the dates of the ammonia violations since nitrate is much more likely to be transported during surface runoff events than ammonia. As shown in Figure 4-13, there are no spikes in nitrate concentrations on these dates at either the QAL005.29 ambient station upstream of the STP or at station QAL004.30 downstream of the STP, so NPS contributions are probably not the source of the elevated ammonia concentrations.

Days Prior to Date of Violation	Date of Ambient Water Quality Violation			
	12-Dec-99	28-Mar-00	29-Jan-01	30-Apr-01
	Precipitation (inches)			
0	0.12	0	0	0
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0.02	0	0.25	0
5	0.23	0	0	0
6	0.75	0.06	0	0
7	0.02	1	0	0
8	0	0.22	0	0
9	0	0	1.2	0.1
10	0.01	0	0.5	0
11	0	0	0.2	0
12	0	0	0.01	0
13	0	0	0	0
14 Day Total	1.15	1.28	2.16	0.1

Table 4-1 Precipitation on the day of and prior to in-stream ammonia violations

In summary, the available data suggest that nonpoint sources of ammonia do not contribute to the ammonia violations. Since the STP is the only significant documented source of ammonia between stations QAL005.29 and QAL004.30, it is believed that the STP is the source of the elevated ammonia concentrations in the impaired section of Quail Run.

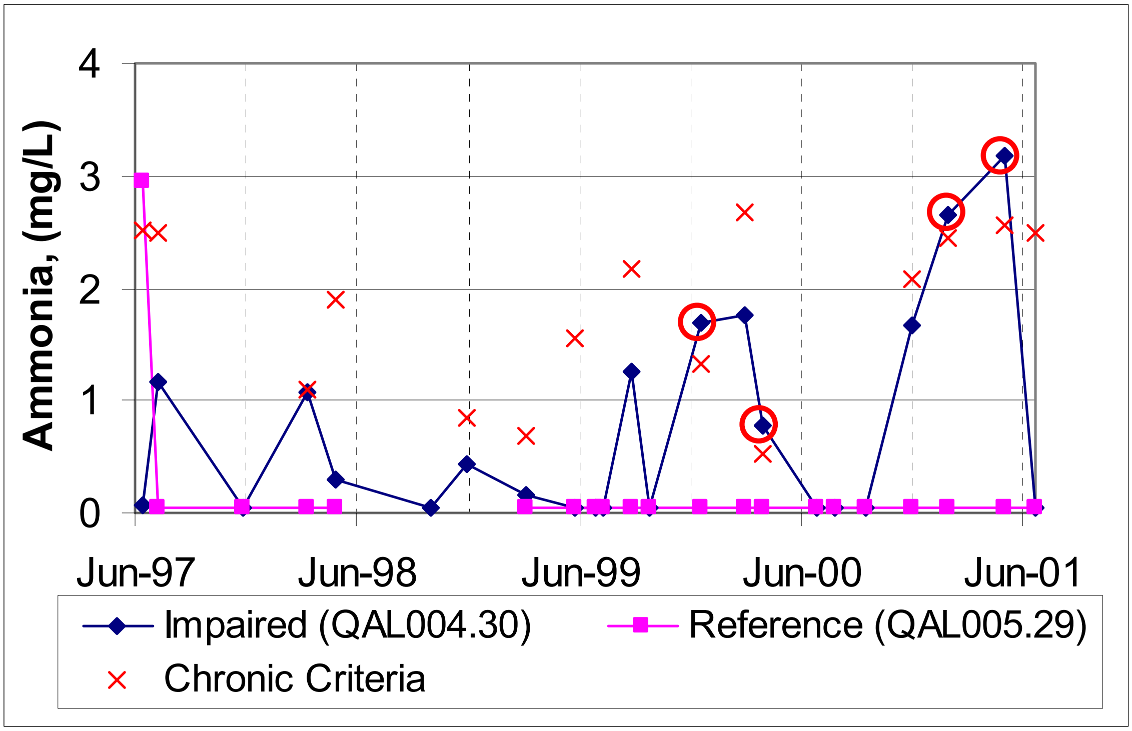

Figure 4-19. Ammonia-N concentration in Quail Run

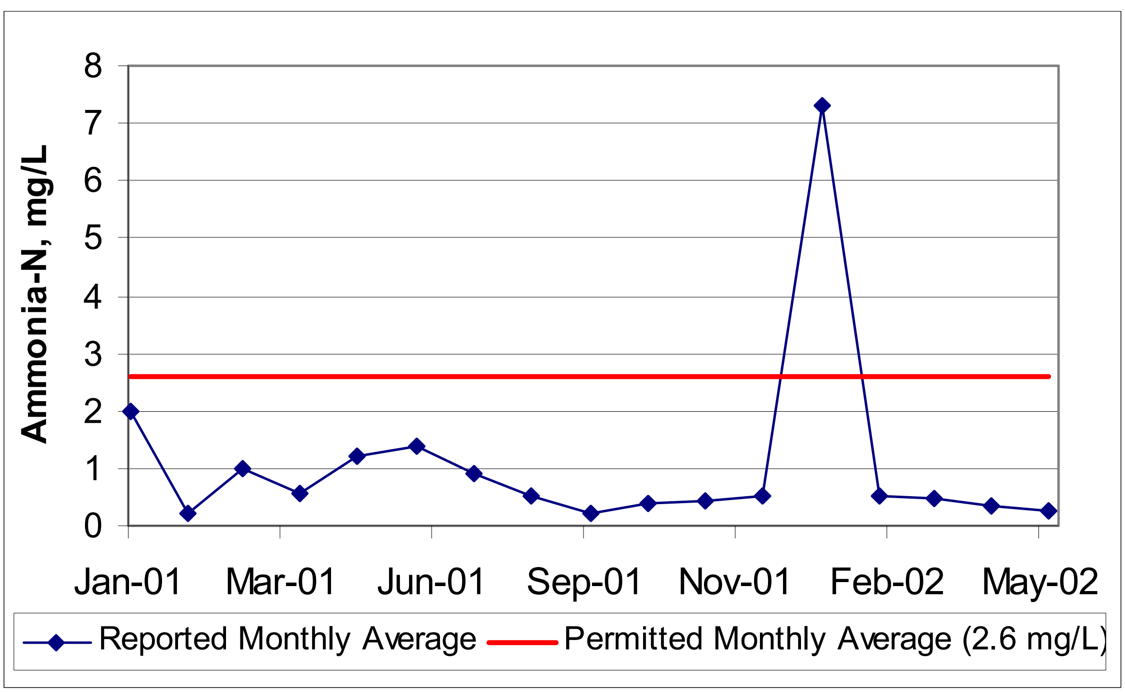

Figure 4-20. Massanutten STP effluent - monthly DMR Ammonia-N.

Residual Chlorine and Chlorination By-Products

Chlorination as practiced at the existing Massanutten STP is the most commonly used method for the destruction of pathogens in sewage effluent that may be harmful to human health. During the chlorination process, chlorine reacts with organic constituents in the wastewater and compounds are formed that may be toxic to aquatic organisms. To reduce these problems, chlorination is followed by dechlorination, a process that is intended to destroy any remaining free residual chlorine and other reactive chlorine by-products. At the Massanutten STP, breakpoint chlorination was practiced during periods of the year when the nitrification reactor was not operating optimally to reduce ammonia discharges. This required chlorine application rates that increased the potential for formation of toxic chlorination by-products. No direct studies had been done to quantitatively determine the presence or concentrations of these compounds in the Massanutten STP effluent or Quail Run itself, but circumstantial evidence indicates that ammonia and chlorination by-products are the likely sources of the historical benthic impairment of Quail Run.

As described in Section 3.6, the existing Massanutten Public Service Corporation STP is being replaced with a new STP to expand the sewage treatment capacity and to eliminate problems associated with the existing STP. Over the years, the VADEQ has investigated several incidences in which operational problems at the existing STP were thought to have caused water quality problems downstream. Cumulatively, these incidences resulted in a VADEQ Consent Special Order in 2002 between the VADEQ and the Massanutten Public Service Corporation to address possible toxic releases from the STP. Incidences that are mentioned in the Consent Special Order include:

- March 15, 1995 fish kill: possibly associated with ammonia releases from the STP.
- April 7, 2001 fish kill: attributed to operating and maintenance deficiencies at the STP

In early 1998, the VADEQ suspected that adverse effects of the Massanutten Public Service Corporation discharge may have been due to breakpoint chlorination. Normal disinfection at the STP used approximately 7 to 10 mg/L of chlorine for disinfection. However, breakpoint chlorination required chlorine concentrations in excess of 100 mg/L. After an initial chronic toxicity test showed the potential for in-stream toxicity, the Massanutten Public Service Corporation was required to conduct quarterly acute and chronic effluent toxicity tests using the Fathead Minnow and the Lesser Water Flea as reference species from August 1998 to May 1999. In August 1998, November 1998, and May 1999, there was no breakpoint chlorination because the ponds and nitrification reactor removed sufficient ammonia for compliance with the STP's permitted ammonia discharge. In February and March 1999, when breakpoint chlorination was being used, four weekly data sets were collected. Data for the toxicity studies are presented in Table 4-2. The data indicate that toxicity was not a problem for the fathead minnow, with or without breakpoint chlorination, (No observable adverse effect concentration (NOAEC) = 97.5% in all data sets). There were no toxicity effects for water fleas in the absence of breakpoint chlorination (NOAEC = 97.5%). However during breakpoint chlorination, NOAECs were 12.5%, 24.4%, 12.5%, and 12.5%, clearly indicating that breakpoint chlorination is a source of effluent toxicity to sensitive in-stream aquatic invertebrates.

Table 4-2. Massanutten STP effluent toxicity test results (Aug. 1998 – May 1999)

Date	Test Organism	Breakpoint Chlorination?	LC50	NOAEC-
8/98	Fathead Minnow	No	>100%	97.5%
8-9/98	Lesser Water Flea	No	>100%	97.5%
11/98	Fathead Minnow	No	>100%	97.5%
11-12/98	Lesser Water Flea	No	>100%	97.5%
2/99 (wk1)	Fathead Minnow	Yes	>100%	97.5%
2/99 (wk1)	**Lesser Water Flea**	**Yes**	**>100%**	**12.2%**
2/99 (wk2)	Fathead Minnow	Yes	>100%	97.5%
2/99 (wk2)	**Lesser Water Flea**	**Yes**	**>100%**	**24.4%**
2/99 (wk3)	Fathead Minnow	Yes	>100%	97.5%
2/99 (wk3)	**Lesser Water Flea**	**Yes**	**>100%**	**12.2%**
3/99 (wk4)	Fathead Minnow	Yes	>100%	97.5%
3/99 (wk4)	**Lesser Water Flea**	**Yes**	**>100%**	**12.2%**
5/99	Fathead Minnow	No	>100%	97.5%

5/99	Lesser Water Flea	No	>100%	97.5%

In support of the TMDL process, the VADEQ initiated an additional chronic toxicity test in August 2002 on Quail Run. Water (grab) samples were collected on August 5, 7, and 9 by VADEQ at Rt. 646 (downstream of the STP) and Rt. 644 (upstream of the STP). These samples were shipped to the USEPA Freshwater Biology Team at the EPA Region 3 lab in Wheeling, West Virginia for processing. The survival/growth of fathead minnows (Pimephales promelas) and the survival/reproduction of Ceriodaphnia dubia were measured using standard toxicity testing methods. The toxicity study reported

> "some evidence of toxicity to either fathead minnows or Ceriodaphnia at both sites. The samples did not affect fathead minnow survival, but the growth of fish exposed to the sample from downstream of the STP was significantly less than the control, while there was no significance difference in growth between the control and the upstream sample. There was no significance difference in survival of Ceriodaphnia between the upstream sample and the control, but the upstream sample adversely impacted the reproductive ability of the Ceriodaphnia, which indicates a toxic effect. The sample from downstream of the STP caused all of the Ceriodaphnia to die within the first 24 hours of the test. Therefore, Quail Run at Rt. 646 (downstream of the STP) is considered extremely toxic to daphnids."

The toxicity study suggests that waters upstream of the STP are somewhat toxic to daphnids. The most likely sources of this toxicity would be runoff containing pesticides and other toxics from turf areas in this portion of the watershed. Even if there is some toxicity in this portion of Quail Run, it is not sufficient to impair the benthic community in the portion of Quail Run upstream of the STP, because the reference benthic monitoring station (QAL005.13) is located in this stretch of the stream and it is not impaired. The toxicity study of samples collected downstream of the STP indicates that this portion of Quail Run is toxic to fathead minnows and daphnids. This suggests that there are toxics in the existing STP effluent that may be responsible for the benthic impairment in Quail Run but the specific toxic compounds are not identified by the toxicity test. However, ammonia, residual chlorine, and chlorination by-products are the most likely causes of the toxicity as discussed previously. Additional toxicity testing and chemical analyses are required to verify these results and to further investigate possible toxic effects on aquatic organisms.

Both the 1998-1999 and 2002 toxicity studies suggest that the effluent from the Massanutten STP is episodically toxic and is probably responsible for the observed benthic impairment in Quail Run. The use of breakpoint chlorination during the colder portions of the year was found to result in toxic discharges that had the potential to adversely affect the benthic community. Because toxicity due to chlorination by-products and elevated ammonia levels are the only clearly identified stressors, the TMDL will be developed for these stressors.

CHAPTER 5: LOAD ALLOCATIONS FOR TOXICS AND AMMONIA TMDL

5.1. Background

The objective of a TMDL is to identify the sources of impairment in a waterbody and allocate allowable loads among different pollutant sources so that the appropriate control actions can be taken to achieve water quality standards (USEPA, 1991). The objective of the TMDL for Quail Run was to determine what reductions in stressor loadings from point and nonpoint sources are required to meet state water benthic water quality standards. The stressor analysis identified ammonia and chlorination by-products as the most probable stressors and the TMDL will be developed for these pollutants. Furthermore, the stressor analysis indicated that the impairment was the result of the point source discharge from the Massanutten STP and no significant nonpoint sources of these stressors were identified. Consequently, the TMDL will be based solely on control of point source loadings from the Massanutten STP.

The TMDL is defined as follows:

$$TMDL = WLA + LA + MOS \qquad [5.1]$$

where:

WLA = wasteload allocation (point source contributions);

LA = load allocation (nonpoint source contributions); and

MOS = margin of safety.

5.2. Existing Conditions

The source of all significant ammonia and chlorination by-product loadings to Quail Run is believed to be the existing Massanutten STP. These loadings are attributed to operational problems with the existing STP, which is described in Section 3.6.1. The primary problem is that the nitrification unit does not work well during cold weather and this has resulted in episodic discharges of ammonia to Quail Run at levels that exceed the plant's operating permit. To control the ammonia discharge during cold weather, the plant utilizes breakpoint chlorination to reduce ammonia in the STP effluent. Breakpoint chlorination requires additions of higher amounts of chlorine than normal, which increases the likelihood that toxic concentrations of chlorination by-products will be produced, even with dechlorination. To meet the general water quality standard applicable to Quail Run, the STP must be improved to reduce ammonia concentrations in the final plant effluent and in the influent to the chlorination unit. In addition, the disinfection process must be operated in such a manner that the discharge of residual chlorine and chlorination by-products is minimized.

5.3. Future Conditions

Because of a need to increase the capacity of the Massanutten STP to handle increased wastewater flows due to expansion of the STP service area and to eliminate suspected operational problems associated with the existing STP, the Massanutten Public Service Corporation has constructed a new STP (see Section 3.6.2) to replace the existing STP. The new STP will utilize an activated sludge process with biological nutrient removal technology that will eliminate violations of the ammonia discharge limits. The discharge of ammonia has been permitted at 2.6 mg/L. The basis for this determination is documented in the permit fact sheet. The new STP will eliminate the use of chlorination by using UV disinfection, except under emergency conditions, and then only for disinfection, not breakpoint chlorination for ammonia control. This should eliminate the discharge of chlorine and chlorination by-products. Under emergency conditions, the STP will be allowed to discharge 0.01 mg/L of total residual chlorine. The Massanutten Public Service Corporation discharge permit is for two flow conditions: 1.5 MGD, which applies to the new STP currently under construction; and 2 MGD if a third treatment train is added in the future. The TMDL is developed for the 2.0 MGD permitted flow.

5.4. Nonpoint Source Load Allocations

As discussed previously, there are no known sources of total residual chlorine in the watershed other than the permitted Massanutten STP. For ammonia, contributions from nonpoint sources were estimated from ambient water quality data collected by the DEQ at the monitoring station QAL005.29, which is upstream of the STP. The land use upstream of this monitoring station is the most developed portion of the watershed and is almost equally divided between residential/urban and forested land use. Ammonia data from this site, which is benthically unimpaired, should reflect NPS contributions of ammonia in the watershed. Ammonia data was collected at this station from July 1997 to June 2001. The 22 reported values were either 0.04 mg/L ammonia-N or they were below the lower detection limit, which was also 0.04 mg/L ammonia-N. Consequently, a conservative mean concentration of 0.04 mg/L ammonia-N was assumed to represent the NPS load concentration.

To estimate a load using the concentration data, it was necessary to estimate a mean annual discharge from the watershed without the contribution from the Massanutten STP. Since Quail Run has no flow gaging stations, flow data from White Oak Run (USGS 01628060, HUC 02070005), which is approximately 15 miles southwest of the Quail Run Watershed, was used to estimate the flow from Quail Run. White Oak Run was the most hydrologically similar watershed within the region of comparable size to Quail Run. It is located on the west slope of the Blue Ridge Mountains near Grottoes, Virginia in Rockingham County and has a drainage area of 1.94 mi^2. The watershed is predominately forested. White Oak Run was monitored by USGS from 1980 to 1995 and the mean annual discharge was 2.76 cfs. Given the 5.49 mi^2 drainage area of Quail Run, and assuming a linear relationship between watershed area and discharge, the mean annual discharge of Quail Run was estimated to be 7.81 cfs. Multiplying the flow value by the ammonia background concentration of 0.04 mg/L with the appropriate units conversions yields an average annual NPS load (LA) of 279 kg/yr of ammonia-N.

5.5. TMDL Allocation Scenarios

For the ammonia TMDL, the point source loading from the STP was identified as the predominant source and a 5% margin of safety is used. The TMDL equation is:

$$TMDL = WLA + LA + MOS \quad [5.2]$$

For the total residual chlorine TMDL, assuming that the chlorination-by products loading to Quail Run are solely the result of the Massanutten STP discharge, the TMDL allocation can be reduced to:

$$TMDL = WLA \quad [5.3]$$

because LA is assumed insignificant and the MOS is assumed to be incorporated implicitly into the WLA. Since the only known source of the total residual chlorine is a single point source, there is little uncertainty in the required reductions, and an explicit MOS is not necessary. The resulting TMDLs for Quail Run are shown Table 5-1.

Table 5-1. TMDLs for Quail Run with permitted Massanutten STP discharge of 2.0 MGD[1]

Pollutant	TMDL (kg/yr)	WLA[2] (kg/yr)	LA (kg/yr)	MOS (kg/yr)
Ammonia	7,857	7,185	279	393
Total residual chlorine	27.63	27.63	0	0

[1] The Massanutten STP permit is tiered. At the other permitted discharge of 1.5 MGD, the WLAs for ammonia and total residual chlorine are 5389 kg/yr and 20.73 kg/yr, respectively.

[2] The wasteload allocations are obtained by multiplying the permitted STP flow by the permitted effluent concentrations of 2.6 mg/L for ammonia and 0.01 mg/L for total residual chlorine (3.7854 L/gal conversion factor). These permitted values are based on monthly and weekly averages, and the basis for this is documented in the permit fact sheets.

5.6. Summary of TMDL Allocation

A TMDL for ammonia and chlorination by-products has been developed for Quail Run. The TMDL addresses the following issues:

1. The TMDL meets the water quality standard based on general standard for benthic macro-invertebrate health. After the plan is fully implemented, the stream will be unimpaired with respect to benthic macro-invertebrate health (nonimpaired or slightly impaired status).
2. The TMDL was developed taking into account all known significant sources of toxics believed to be contributing to the impairment.

3. The margin of safety (MOS) was 5% for ammonia and implicit in the wasteload allocation for total residual chlorine because the TMDL allocation applies to a single known source that can be controlled.
4. The TMDL is applicable to both high- and low-flow stream conditions, but the TMDL was developed specifically for low flow conditions, which are the critical conditions for a point source dominated TMDL.
5. The flow regime in Quail Run is seasonal but the source of pollutants causing the impairment is relatively constant because of its point source origin. The TMDL focuses on the critical low flow conditions, which typically occur during the summer months, because the impairment is caused by a point source.
6. The selected TMDL allocations restrict the ammonia and total residual chlorine loadings to levels that are protective of benthic macro-invertebrate health as determined by VADEQ. Under normal STP operating conditions, there will be no discharge of total residual chlorine or chlorination by-products to Quail Run.

5.7. TMDL Implementation Process

The goal of this TMDL is to develop a plan that will lead to expeditious attainment of the water quality standards. The first step in this process is to develop an implementable TMDL. The second step is to develop a TMDL implementation plan, and the final step is to implement the TMDL. In the Quail Run TMDL, the identified source of the impairment was the existing Massanutten Public Service Corporation STP. The Massanutten Public Service Corporation has constructed and began operating a new STP in February 2003 that should eliminate the cause of the impairment. Consequently, an implementation plan is not necessary as steps have already been taken to eliminate the source of the impairment.

In addition to the allocations in Table 5-1, the recent excessive growth of periphyton in the stream immediately downstream of the STP outfall is an indication that nutrient discharges from the existing plant may contribute to the stream's impairment. A TMDL allocation was not developed for nutrients (specifically phosphorus), because the periphyton growth was recent and believed to be largely the result of changes in the riparian forest canopy downstream of the STP. In addition, the new STP will reduce nutrient loadings to Quail Run and this may also further reduce the periphyton problem. It is recommended that a forested riparian canopy be reestablished in the disturbed riparian zone downstream of the STP to increase stream shading during the late spring to fall period. The Massanutten development is currently investigating costs associated with reestablishing the riparian canopy and is expected to enter into an agreement with VADEQ to partially restore the riparian canopy downstream of the STP.

5.8. Follow-Up Monitoring

VADEQ will continue sampling at the established benthic monitoring station (QAL004.30) in order to evaluate the effects of reductions in ammonia and elimination of chlorination by-products on the health of the benthic community. Ambient water quality monitoring, particularly of nutrients (a potential contributor to the impairment), should also be continued in case reductions in ammonia and chlorination by-products do not improve the health of the benthic community. Periphyton levels should also be assessed as they appear to be a good indicator of nutrient loadings in Quail Run. It is expected that the periphyton levels in Quail Run will decline as the riparian canopy is restored in the area downstream of the STP.

Based on the results of EPA's chronic toxicity study for Quail Run, additional toxicity testing and chemical analyses are recommended to verify these results and to further investigate possible toxic effects on aquatic organisms. Monitoring studies may also include the initiation of a special study and/or monitoring of fish tissue. As with other pollutants, if toxic chemicals are found to exist at toxic levels in these streams in the future, then TMDLs will be developed for these constituents as well.

CHAPTER 6: PUBLIC PARTICIPATION

Public participation was elicited during the TMDL development process in order to receive inputs from stakeholders and to apprise the stakeholders of the progress made. On May 2, 2002, members of the Virginia Tech TMDL group traveled to Rockingham County to become acquainted with the watershed. During that trip, they spoke with various stakeholders.

Two telephone conferences were held with representatives from the primary stakeholder, the Massanutten Sewage Treatment Plant. Representatives from VADEQ, VADCR, and USEPA were also present at these conferences, held October 10, 2002 and January 3, 2003.

Because of the point source nature of the impairment and the high degree of confidence in the pollutants causing the impairment, a single public meeting was public noticed on January 27, 2003 and held on February 10, 2003 at Spotswood High School in Penn Laird, Virginia to inform the stakeholders of TMDL development process and to obtain feedback on the first draft of the TMDL report. Copies of the TMDL report, presentation materials, and diagrams outlining the development of the TMDL were available for public distribution at the meeting. Approximately 18 people attended the meeting. The public comment period ended on March 12, 2003. Two comments were received during the comment period.

CHAPTER 7: REFERENCES

Roberts, C. and C.M. Bailey. 2003. The Geology of Virginia. (<http://www.wm.edu/geology/virginia/>).

SCS. 1982. Soil Survey of Rockingham County, Virginia. Richmond, Va.: USDA-SCS.

SERCC (Southeast Regional Climate Center). 2000. South Carolina Department of Natural Resources, Water Resources Division, 1201 Main Street Suite 1100, Columbia, SC 29201. (<http://water.dnr.state.sc.us/climate/sercc/products /normals/442208_30yr_norm.html>)

USEPA. 1991. Guidance for Water Quality-based Decisions: The TMDL Process. EPA 440/4-91-001. Washington, D.C.: Office of Water, USEPA.

USEPA. 1998. Water Quality Planning and Management Regulations (40 CFR Part 130) (Section 303(d) Report). Washington, D.C.: Office of Water, USEPA.

USEPA. 2000. Stressor Identification Guidance Document. EPA 822/B-00/025. Washington, D.C.: Office of Water, USEPA.

USEPA. 2002. Mid-Atlantic Ecoregions. (<http://www.epa.gov/ceisweb1/ceishome/atlas/maiaatlas/mid_atlantic_ecoregions.html>)

SWCB. 2002. Water quality standards. 9 VAC 25-260-5 et seq. Includes amendments effective as of June 5, 2002. State Water Control Board. Richmond, Va.

VADEQ. 2002. 2002 303(d) Report on Impaired Waters. Richmond, Va.: VADEQ. (<http://www.deq.state.va.us/water/303d.html>)

VADEQ. 1998. 1998 303(d) Report on Impaired Waters. Richmond, Va.

VWCB. 1985. Ground Water Map of Virginia, ed. P.J. Smith and R.P. Ellison. Richmond, Va.: Virginia Water Control Board (VWCB) Ground Water Program.

Woods, A.J., J.M. Omernik, D.D. Brown. 1999. Level III and IV Ecoregions of Delaware, Maryland, Pennsylvania, Virginia, and West Virginia. Corvallis, Or.: USEPA. (<ftp://ftp.epa.gov/wed/ecoregions/reg3/FinalFullRgnIIIText3>).

APPENDIX A.

Glossary of Terms

Allocation
That portion of a receiving water's loading capacity that is attributed to one of its existing or future pollution sources (nonpoint or point) or to natural background sources.

Allocation Scenario
A proposed series of point and nonpoint source allocations (loadings from different sources), which are being considered to meet a water quality planning goal.

Background levels
Levels representing the chemical, physical, and biological conditions that would result from natural geomorphological processes such as weathering and dissolution.

Best Management Practices (BMP)
Methods, measures, or practices that are determined to be reasonable and cost-effective means for a land owner to meet certain, generally nonpoint source, pollution control needs. BMPs include structural and nonstructural controls and operation and maintenance procedures.

Calibration
The process of adjusting model parameters within physically defensible ranges until the resulting predictions give a best possible good fit to observed data.

E-911 digital data
Emergency response database prepared by the county that contains graphical data on road centerlines and buildings. The database contains approximate outlines of buildings, including dwellings and poultry houses.

Hydrology
The study of the distribution, properties, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.

Instantaneous criterion
The instantaneous criterion or instantaneous water quality standard is the value of the water quality standard that should not be exceeded at any time. For example, the Virginia instantaneous water quality standard for fecal coliform is 1,000 cfu/100 mL. If this value is exceeded at any time, the water body is in violation of the state water quality standard.

Load allocation (LA)
The portion of a receiving water's loading capacity that is attributed either to one of its existing or future nonpoint sources of pollution or to natural background.

Margin of Safety (MOS)
A required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the receiving waterbody. The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models). The MOS may also be assigned explicitly, as was done in this study, to ensure that the water quality standard is not violated.

Nonpoint source
Pollution that is not released through pipes but rather originates from multiple sources over a relatively large area. Nonpoint sources can be divided into source activities related to either land or water use including failing septic tanks, improper animal-keeping practices, forest practices, and urban and rural runoff.

Pathogen
Disease-causing agent, especially microorganisms such as bacteria, protozoa, and viruses.

Point source
Pollutant loads discharged at a specific location from pipes, outfalls, and conveyance channels from either municipal wastewater treatment plants or industrial waste treatment facilities. Point sources can also include pollutant loads contributed by tributaries to the main receiving water stream or river.

Pollution
Generally, the presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the Clean Water Act for example, the term is defined as the man-made or man-induced alteration of the physical, biological, chemical, and radiological integrity of water.

Runoff
That part of rainfall or snowmelt that runs off the land into streams or other surface water. It can carry pollutants from the air and land into receiving waters.

Total Maximum Daily Load (TMDL)
The sum of the individual wasteload allocations (WLA's) for point sources, load allocations (LA's) for nonpoint sources and natural background, plus a margin of safety (MOS). TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures that relate to a state's water quality standard.

Validation (of a model)
Process of determining how well the mathematical model's computer representation describes the actual behavior of the physical process under investigation.

Wasteload allocation (WLA)
The portion of a receiving water's loading capacity that is allocated to one of its existing or future point sources of pollution. WLAs constitute a type of water quality-based effluent limitation.

Water quality standard
Law or regulation that consists of the beneficial designated use or uses of a water body, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular water body, and an anti-degradation statement.

Watershed
A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.